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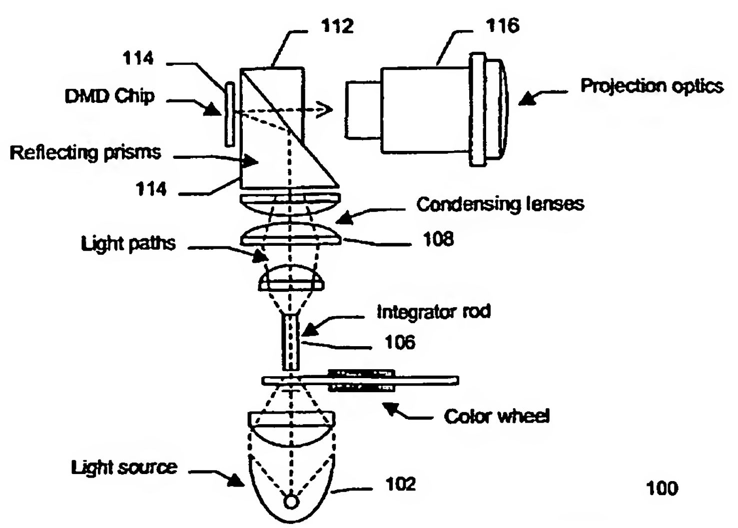
(54) **Title:** DIGITAL LIGHT PROCESSING BASED 3D PROJECTION SYSTEM AND METHOD




**Prior Art Single-Chip DMD Projection System – Example 1**

(57) **Abstract:** This application is related to video projection using digital light processing techniques and in particular to stereoscopic video projection. A digital micro-mirror device based 3D projection system has a 3D data system coupling 3D images to an electrical input of a color system and digital micro-mirror display device and a 3D optical system coupling an output of a light source through an optical path comprising said digital micro-mirror display device, a 3D optical encoder and projector optics to a display medium; wherein said 3D projection system displays 3D images onto said display medium. The data system includes at least two front end processing portions, a 3D data formatter, a digital micro-mirror device data formatter and a digital micro-mirror display device. Such 3D data system provides color system control signals to a color system and 3D encoder as well as digital micro-mirror display data to said digital micro-mirror display device. A method of converting a digital micro-mirror device based 2D projection system to a digital micro-mirror device based 3D projection system includes installing a 3D data formatter, installing a digital micro mirror device data formatter, optionally replacing an existing color wheel with a color wheel formatted for 3D; and installing 3D optical encoder system in one of three positions in an optical path of said system.

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# DIGITAL LIGHT PROCESSING BASED 3D PROJECTION SYSTEM AND METHOD

## Related Applications

The present application is related to a provisional application serial number 60/239,664 filed on October 12, 2000 entitled DLP Based 3D Projection System and to another provisional application serial number 60/261,136 filed on January 12, 2001 entitled Method and apparatus for stereoscopic display using digital light processing. Both of these references are incorporated herein by this reference.

## Field of Invention

This application is related to video projection using digital light processing techniques and in particular to stereoscopic video projection.

## Background of the Invention

Digital light processing (DLP) technology from Texas Instruments has been proven a viable and reliable technology for use in data and multimedia image projection systems. The basis of the DLP technology is the Digital Micro-mirror Device (DMD) also from Texas Instruments as described in numerous patents, but in particular described by Hornbeck in US Patent 4,566,935 hereby incorporated by reference. The DMD chip is a micro electro-mechanical system (MEMS) consisting of an array of bi-stable mirrors fabricated over a CMOS memory substrate. Projection systems based on this technology vary in configuration and include one-chip, two-chip, and three-chip DMD designs. Special properties of the DMD chip and the method by which light is modulated by the mirrors afford the possibility of developing a 3D stereoscopic projection system based on the DMD technology. A 3D stereoscopic projection system has the ability to deliver left and right eye views of an image to multiple people thus creating the illusion of depth for groups of people. The DLP based 3D stereoscopic projection system described here provides many benefits including low crosstalk between left-eye right-eye information, high brightness, low flicker, and compactness.

## Single Chip DMD Projection Systems

Single-chip projector systems utilize a single DMD (digital micro-mirror device) chip and a color wheel to display full color images. The DMD chip reflects light passing through the color wheel either through the projection lens system onto a projection screen or back through the color wheel into the light source. Since the DMD chip consists of thousands of tiny micro-electromechanical mirrors, the chip itself does not regulate color. For this reason a color wheel that consists of at least three primary colors (e.g., red, green, and blue) is used to modulate the light source color. The color is modulated at a rate faster than is discernable by the human eye, thereby causing a full color effect. The intensity of the light that is reflected by each pixel (micro-mirror) of the DMD chip is control by a pulse-width modulation scheme. This scheme is more fully described in "Pulse width modulation control in DLP projectors," 115-121 TI Technical Journal, July-September 1998, by Don Doherty and Greg Hewlett and hereby incorporated by reference. The DMD chip consists of a complicated micro-mechanical mirror system constructed over a CMOS memory substrate. As described in Digital light Processing for High Brightness, High Resolution Applications, pg. 4 by Larry J. Hornbeck from Texas Instrument website, www.ti.com/dlp white paper section and hereby incorporated by reference. To display a single image frame from a video or computer source on the DMD chip, mirror state information is written to the CMOS substrate of the DMD chip in blocks or groups. Once a block of memory is written, each mirror above the block is updated to its new state. This process continues block by block until each mirror in the chip is updated. At the end of the frame, all mirrors on the chip are reset to the "OFF" position at the same time. That is, each mirror is directed to reflect light back into the optical source. The fact that all mirrors on the DMD chip are reset to "OFF" at the end of a chip update makes the DMD chip eminently suitable as a light valve for 3D stereoscopic projection systems as will be explained below.

Figure 1 illustrates a typical single chip DMD projector optical design 100 by Texas Instruments as described in " From cathode rays to digital micromirrors: A history of electronic projection display technology", Larry J. Hornbeck, pg. 40, TI Technical journal, July-September 1998 and hereby incorporated by reference. In this design an elliptic mirror and condenser lens 102 projects light through the color wheel 104 and into an integrator rod 106. A second condensing

lens system 108 gathers light exiting from the integrator rod 106. Two reflecting prisms 110 and 112 are used to reflect this light onto the DMD chip 114 that, in turn, reflects light out through the projection optics 116 and onto a view screen (not shown).

Figure 2 illustrates an alternative DMD projector configuration 200 used by Plus Corporation. This design is simpler in that it does not utilize reflecting prisms. In this design light passes from an elliptic mirror through a color wheel 204 and is collected by a condensing lens system. The light is then reflected from a fixed mirror 208 up to the DMD chip 210, from whence it is reflected out through the projection optics 212 as dictated by the image being displayed.

The designs represented by Figure 1 and Figure 2 is not the only possible ways in which a single chip DLP projection system can be configured. These figures are included for illustrative purposes only and do not in any way limit the applicability of this invention to other single chip DLP configurations using a single DMD chip and a color wheel.

Figure 3 Illustrates a three-segment color wheel configuration 300 for a single chip DLP projection system. This wheel design consists of a wheel hub 302 and a translucent region consisting of three separate color filters, red 304, green 306, and blue 308. DLP projection systems utilizing the three-color color wheel split each image into three separate color components that are displayed sequentially in time and that correspond to the color filters on the wheel. In the case of a 60Hz video source input to the projector, the image is split into its red, green, and blue components and displayed at a rate of 180Hz.

Figure 4 Illustrates a four-segment color wheel configuration 400 for single chip DLP projection systems. This wheel design enables the projector to display brighter white images by adding a clear filter 402 to the color wheel 404 in addition to the red 406, green 408, and blue 410 color filters. In this configuration, each primary color (red, green, and blue) subtends the same angle while the white section subtends a slightly smaller angle than the color filters.

Figure 5 illustrates an illustrative block diagram of the video processing system for a DLP projector as more fully described in "Video Processing for DLP™ Display Systems" by Clantanoff T. Markandy and G. Pettitt from Texas Instruments website, www.ti.com/dlp, white paper section and hereby incorporated by reference. Information flow in this diagram is from left to right. In this illustrative system a video source input is supplied on the extreme left. The video source 502 can be component, composite, NTSC, Y/C, PAL, or any other video format for which the projector has been designed to receive. The Font-End Video Processing block 504 handles the initial conditioning and interpretation of the incoming video signal. The most important step in this block is the conversion of the analog video signal to digital data. Since the DMD chip is an inherently digital device, typically all video processing inside the projector is done digitally. Another important step is the conversion of the video signal to Y/C or chrominance/luminance format.

The second block in the video process is the Interpolation Processing block 506. Since DMD chip devices have a higher pixel resolution than the incoming video data (e.g., 800x600, or 1024x768 pixels wide by pixels high) the video signal must be re-sampled at the higher resolution. Further, since many video formats are "interlaced", that is all odd lines are displayed and then all even lines are displayed, the signal must be converted from interlaced to progressive scan. Progressive scan means that data is displayed in the order that it comes from the top to the bottom (or *vice versa*) in a single scan or sweep. Since the DMD chip is a progressive scan device a progressive scan conversion must be performed on the video signal. Because of the way in which 3D stereoscopic images are transmitted in video signals it is possible for the Interpolation Processing block to degrade or scramble the left-eye and right-eye information carried in the video signal, depending on the algorithm implemented for the progressive scan conversion step. This will be discussed in greater detail below.

The final step, Back-End Processing 508, splits the video input image or computer input image into the proper color space representation. That is, for the wheel show in Figure 3, the image is split into red, green, and blue components. For the wheel of Figure 4 the image is split into red,

green, blue, and white components. The output of this step is color space image information acceptable by the DMD chip driver circuitry 510.

### Dual Chip DMD Projection Systems

Dual-chip DMD projection systems are rare or non-existent in the market place. The idea was to use two DMD display chips and a two-color color wheel to display a full color image. The disadvantages of this system include added complexity due to the management of two DMD displays and retention of a mechanical color wheel filter system, among others.

### Three Chip DMD Projection Systems

Three-chip DMD projection systems are gaining popularity in the large venue market. They consist of a complex optical prism system used to illuminate three separate DMD display chips. The disadvantage of these systems is the higher cost of the multiple display devices and the more complicated optics. Advantages include the capacity for greater brightness and a reduction in complexity due to the absence of a mechanical color wheel filter.

### Existing Stereoscopic Projection Systems

Other 3D projection systems include micropolarizer (μPol) based projection systems; dual projectors and CRT based projection systems with a Z-Screen. Many of these are the subject of one or more patents or patent applications by the assignee of this application VRex, Inc. or its parent Reveo, Inc.

### Christie and Barco Digital Three Chip Stereoscopic DLP™ Projection System

Shortcomings of other projection systems and of the Christie and Barco3D DLP projection system include the fact that the projector output is synchronized to the input. This means that the rate at which the projector displays the sequence of left and right images is the same is the input vertical synchronization signal. The result is that in order to reduce or eliminate flicker in the projected image, the input image source must be driven at a very high frame rate. An advantage of the present invention over prior art systems is that the input frame rate and the output frame rate can be completely decoupled, eliminating the need for expensive high-end computer equipment required to generate the high frame-rate images.

### Off-The-Shelf Micro-Mirror Projection Systems

There are several brands of off-the-shelf DLP projection systems that have been found to support a form of "page-flipped" 3D output without any modifications. To view stereoscopic 3D images with such projectors, a pair of liquid crystal shutter glasses may be synchronized to the video input source or to the RGB computer input source. The major shortcoming of this solution is that the maximum input frame rate for the RGB computer input is typically 85Hz (42.5Hz per eye) and is not high enough to avoid noticeable flicker. This fact is also true for the video input that is fixed at around 60Hz (30Hz per eye). Another shortcoming is the fact that the flicker rate of the output is dependent on the input data frame rate.

### The Problem

The fundamental problem of stereoscopic imaging is the display of two perspective images in such a way that they appear simultaneous to an observer and in such a way that the each eye sees only the corresponding perspective image. There are many systems in existence that provided this capability for stereo viewing by various different methods. The problem solved by this invention is the display of high-quality 3D stereoscopic images using a digital micro-mirror based optical system. Further, the present invention provides a means and apparatus to interpolate 3D image data from any input signal resolution to the display resolution without corruption due to the mixing of left-right perspective image data. All major stereoscopic data formats are supported. Further the present invention provides a system whereby 3D image decoding may be accomplished through one of three different decoding methods including passive linearly polarized eyewear, passive circularly polarized eyewear, active shutter glass eyewear or color filter based glasses. In the preferred embodiment the user may switch between any of the 3D optical encoding methods by simply changing an external filter assembly.

Micro-mirror display technology (such as that developed by Texas Instruments) is well suited to the present invention because of its fast switching times and extremely low persistence compared to liquid crystal based display technologies such as polysilicon, DILA™ (digital image light amplifier), and LCOS (liquid crystal on silicon). These properties that are inherent to DMD technology help to reduce stereoscopic crosstalk (the observed light leakage between left and right perspective views) in ways that are not possible by other 3D methods. Further, unlike some

other 3D methods this invention permits the operation of the 3D projector in both stereoscopic and non-stereoscopic modes without any physical hardware or software changes required in switching between the two viewing methods. In addition to the 3D enhancements to DMD projectors, one aspect of the invention also has the capability of enhancing the brightness of 3D projection systems. This benefit is derived from the cholesteric liquid crystal reflective coatings used on certain color wheels variations and used as a stand-alone polarization plate.

## Brief Description of the Drawings

Figure 1 illustrates a first example of a prior art single-chip DMD projection system;

Figure 2 illustrates a second example of a prior art single-chip DMD projection system;

Figure 3 illustrates a three-segment color wheel for single chip DMD projection systems;

Figure 4 illustrates a four-segment color wheel for single chip DMD projection systems;

Figure 5 illustrates a prior-art DMD projector video processing block diagram for single-chip DLP projector;

Figure 6 illustrates the signal flow and optics block diagram for a DMD based 3D projection system;

Figure 7 illustrates the block diagram of a 3D data formatter;

Figure 8 illustrates the block diagram of a DMD data formatter;

Figure 9 illustrates a DMD data formatter chart for Input Synchronized Frame Sequential3D Input using Four Segment Color Wheel (chart applies to 75Hz, 80Hz, 85Hz input signals);

Figure 10 illustrates a DMD data formatter chart for Input Synchronized Frame Sequential 3D Input using Three- Segment Color Wheel (chart applies to 72Hz, 75Hz, 80Hz input signals);

Figure 11 illustrates Input Synchronized Color Sequential 3D using a Three Segment Color Wheel and Quad Frame Buffer (chart applies to 72Hz, 75Hz, and 80Hz input signals);

Figure 12 illustrates Input Synchronized Color Sequential 3D using a Six-Segment color Wheel and Quad Frame Buffer (chart applies to 72Hz, 75Hz, and 80Hz input signals);

Figure 13 illustrates a DMD formatter chart for Output Synchronized Frame Sequential 3D format for 60Hz Input using a Four-Segment Color Wheel;

Figure 14 illustrates a DMD formatter chart for Output Synchronized Frame Sequential 3D format for 120Hz Input using a Four-Segment Color Wheel;

Figure 15 illustrates a DMD formatter chart for Output Synchronized Frame Sequential 3D format for 60Hz Over-Under 3D Input using a Four-Segment Color;

Figure 16 illustrates a DMD formatter chart for Output Synchronized Color Sequential 3D format for 120Hz Color-Sequential 3D Input, using a Three-Segment Color Wheel;

Figure 17 illustrates a cholosteric liquid crystal reflective circular polarizing red filter (similar for white, green, or blue);

Figure 18 illustrates the Spectral Response for a CLC Filter/Circular Polarizer;

Figure 19 illustrates a Three-Segment Color Wheel type CW-A;

Figure 20 illustrates a Three-Segment Color Wheel type CW-B;

Figure 21 illustrates a Six-Segment Color Wheel type CW-C

Figure 22 illustrates a Six-Segment Color Wheel type CW-D;

Figure 23 illustrates a Six-Segment Color Wheel type CW-E;

Figure 24 illustrates a Four-Segment Color Wheel type CW-F;

Figure 25 illustrates a Four-Segment Color Wheel type CW-G;

Figure 26 illustrates a Eight-Segment Color Wheel type CW-H;

Figure 27 illustrates a Eight-Segment Color Wheel type CW-I;

Figure 28 illustrates a Eight-Segment Color Wheel type CW-J;

Figure 29 illustrates a Liquid Crystal Rotator with no Applied Terminal Voltage;

Figure 30 illustrates a Liquid Crystal Rotator with no Applied Terminal Voltage;

Figure 31 illustrates a DMD based stereo 3D projector, 3D optical Configurations: A, B, H, I, K, M, N, S, U and W;

Figure 32 illustrates a DMD based stereo 3D projector, 3D optical configurations: C and O;

Figure 33 illustrates a DMD based stereo 3D projector, 3D optical configurations: D and P;

Figure 34 illustrates a DMD based stereo 3D projector, 3D optical configurations: E and Q;

Figure 35 illustrates a DMD based stereo 3D projector, 3D optical configurations: F, G, J, L, R, T and V;

Figure 36 illustrates passive 3D glasses (linear or circular polarized);

Figure 37 illustrates a diagram of a typical LC shutter operation (shutter passing light);

Figure 38 illustrates the use of LC shutter glasses in stereoscopic visualization; and.

Figure 39 illustrates a conceptual diagram of a switchable color filter for eyewear used to decode color-sequential 3D formats.

## Summary of the Invention

A digital micro-mirror device based 3D projection system has a 3D data system coupling 3D images to an electrical input of a color system and digital micro-mirror display device and a 3D optical system coupling an output of a light source through an optical path comprising said digital micro-mirror display device, a 3D optical encoder and projector optics to a display medium; wherein said 3D projection system displays 3D images onto said display medium. The data system includes a least one front end processing portions, a 3D data formatter, a digital micro-mirror device data formatter and a digital micro-mirror display device. Such 3D data system provides color system control signals to a color system and 3D encoder as well as digital micro-mirror display data to said digital micro-mirror display device.

The system of has a front end processing including a analog to digital conversion of the input data, luminance to chroma separation of the data, chroma demodulation of the data, color space conversion of the data, a de-gamma process of the data and error diffusion of the data.

The 3D data formatter includes a 4:2 RGB Input Data Switch/router coupled to two video processors each coupled to a memory system, a microcontroller is coupled to the 4:2 RGB input data switch/router, to the video processors and to a 2:2 RGB output data switch router and an output of each video processor is coupled to the 2:2 RGB output data switch router.

The digital micro-mirror device data formatter includes a dual port memory controller coupled to a memory, a digital micro-mirror data converter and a Microcontroller. The digital micro-mirror data converter provides output digital micro-mirror device data and the microcontroller provides control signals to the dual-port memory controller, the digital memory device data converter and a color wheel controller as well as 3D field signal.

The digital micro-mirror display device is a micro electro-mechanical system having an array of bi-stable mirrors fabricated over a CMOS memory substrate. The display device modulates an inputted light with a movement of said mirrors commanded by the digital micro-mirror device data.

The optical system of the 3D projection system includes a subsystem including a lamp, a condensing system, integrating optics coupling light to a color system. The color system

selectively transmits light of at least three primary colors. The digital micro-mirror display device selectively transmitting a plurality of pixels of selected color information. A 3D encoder system is placed in one of three positions in the light path of said 3D projector system. A projection optics system that transmits said 3D image on to a display medium and a 3D optical decoder system selecting a left image and a right image from the 3D image for use by an observer using the 3D optical decoder.
The color system is a color wheel with color filters. There are ten types of color wheels that may be used in a 3D projector system described herein.

The digital micro-mirror display device comprises a micro electro-mechanical system having an array of bi-stable mirrors fabricated over a CMOS memory substrate wherein said display device modulates an inputted light with a movement of said mirrors commanded by a digital micro-mirror device data.

The first 3D encoder location is located between said integrating optics and the digital micro-mirror display device and include means for encoding 3D images for transmissions said means selected from the group consisting of linear polarization, circular polarization, color sequential encoding, and time-sequential encoding.

The second 3D encoder location is located between said digital micro-mirror display device and said projector optics and comprises means for encoding 3D images for transmissions said means selected from the group consisting of linear polarization, circular polarization, color sequential encoding, and time-sequential encoding.
The third 3D encoder location is located between said projector optics and display medium either physically within said projector or mounted externally to said projector comprises means for encoding 3D images for transmissions said means selected from the group consisting of linear polarization, circular polarization, color sequential encoding, and time-sequential encoding. The 3D optical decoder includes eyeglasses having active elements or passive elements.

A method of converting a digital micro-mirror device based 2D projection system to a digital micro-mirror device based 3 D projection system includes installing a 3D data formater; installing a digital micro mirror device data formatter; optionally replacing an existing color

wheel with a color wheel formatted for 3D; and installing 3D optical encoder system in one of three positions in an optical path of said system.

## Detailed Description of the Invention

A representative system diagram of the present invention 600 is found in Figure 6. The diagram demonstrates both the data flow and optical image flow of the system. The optical image flow is demonstrated by the term "light" and flows in the vertical direction with the exception of the bottom of the flow. Data flow is represented as horizontal channels starting on the left side of the figure and proceeding to the right. Starting in the upper left hand quadrant of the figure, the diagram illustrates four separate inputs; two for RGB (computer) 602 and 604 and two for video 606 and 608. Other input types are possible. For the video inputs, any or all of the three major video formats including composite, S-video, or component, may be implemented. To accommodate the widest variety of inputs possible, the preferred embodiment provides a total of eight separate inputs including left and right RGB, left and right composite video, left and right S- video, left and right component video.

To accommodate this number of inputs each of the Front-End Video Processing blocks 614, and 616 is capable of supporting three separate input formats, including composite video, S-video, and component video. Many modern video decoder chips support this level of functionality. The Front-End Video Processing blocks also handle analog-to-digital conversion (ADC) of the input video signals. Regardless of the input format, the output of the 3D Image Front-End RGB or Video Processing Block is a digital version of the selected input. The digital signal may take any of the standard digital video data formats including YUV 4:2:2, 24-bit RGB, 48-bit RGB, etc., depending on the price-performance requirements. The 3D format of the input image data may take any of the standard forms. For video input signals the 3D format is typically field sequential 3D (left-right image data are transmitted on alternate fields of the video signal) or dual input 3D (left-right image data are input on two physically separate input connectors). Other functions of the Front-End RGB or Video Processing blocks 610, 612, 614, or 616 include gain control, color and brightness control, video format decoding (NTSC, PAL, SECAM, etc.) and other features that may be associated with video signal decoding.

The Front-End RGB Processing blocks 610 and 612each support the input of three separate color channels (red, green, and blue) as well as two synchronization signals (vertical and horizontal). Each of the front-end processing blocks is used to convert an analog video or computer signal into a standardized digital format. In the preferred embodiment all analog inputs are converted to the 24-bit RGBHVC (red, green, blue, horizontal sync, vertical sync, and pixel clock) digital format. Numerous other digital formats could be chosen as well depending on the desired price-performance factors. There are a wide variety of 3D formats for computer RGB input including page-flipped (left-right image data are transmitted on alternate video frames of a single physical channel), over-under (left-right image data are transmitted on the top and bottom halves of a single video frame in one physical channel), side-by-side (left-right image data are transmitted on left and right halves of a single video frame in one physical channel), row-interleaved (left-right image data are transmitted on alternate rows of a single video frame in one physical channel), column-interleaved (left-right image data are transmitted on alternate rows of a single video frame in one physical channel), and dual-input (left-right image data are transmitted on two physically separate channels).

The 3D Data Formatter block 618 performs several major functions including input channel selection, stereoscopic demultiplexing, stereoscopic image scaling, scan rate conversion, and stereoscopic 3D format conversions. Based on input selection settings, the 3D Data Formatter chooses which of the four input channels to use for 3D stereoscopic input. Typically only one or two channels will be chosen at a time depending on which 3D format is being input. Next the 3D Data Formatter demultiplexes or separates 3D stereoscopic data into two separate image-processing channels. It is extremely important that this separation step be performed so that the left-perspective image data and right-perspective image data may be processed separately. Processing the channels together as one data frame will cause corruption of the data during the image scaling and scan conversion processes. Next the 3D Data Formatter 618 performs an image scaling operation to adjust the image resolution to that required by the DMD Data Formatter. Typically the resolution corresponds to the native resolution of the DMD display but may vary in some instances. Depending on the data format chosen for communication with the

DMD Data Formatter, the 3D Data Formatter may perform a scan conversion of the image data. If the output data format is Input Synchronized no scan conversion is performed. This is the case where the input data signal frame rate controls the internal data frame rate of the system and where the 3D output rate of the projector is directly controlled by the input signal. If the output data format is Output Synchronized, a scan conversion is performed to synchronize the processed 3D image data with the projector optical output frame rate. In this case the 3D output rate of the projector is completely independent of the input signal frame rate. There are advantages and disadvantages for both methods. Finally the 3D Data Formatter 618 performs a 3D stereoscopic format conversion to recombine the processed stereoscopic image data into the format required by the DMD Data Formatter 620. Many possibilities exist for the 3D format of this data output depending on several factors including the method used to implement the DMD Data Formatter 620, the method used to display 3D image data, and the method used to optically encode the left- and right-perspective images.

The primary purpose of the DMD Data Formatter 620 is to convert processed 3D stereoscopic image data in the RGBHVC format into the data and control signals required to drive the DMD display 622 in the chosen 3D Display Format. A secondary purpose is to control the color management system that drives the color wheel filter. A tertiary purpose is to provide a 3D Field signal output to synchronize the 3D Encoder system with the 3D image data display. There are numerous variations for the means and apparatus to implement the DMD Data Formatter depending on the 3D optical encoding method and the 3D Display Format chosen. The choice of which method to use depends on the desired application as well as price-performance factors.

The DMD Display 622 encodes digital electronic data into an optical image. It consists of hundreds of thousands of bi-stable microscopic mirrors that reflect light either out through the projection lens system or back into the light engine. Grayscale images are achieved by pulse-width modulation of individual mirror pixels. The speed at which the mirrors change is orders of magnitude faster than the speed of liquid crystal based displays making the DMD display ideal for use with time-sequential 3D display systems. The DMD Display required by the present

invention is not fundamentally different that those currently used in projection industry. This concludes the summary overview of the data flow aspect of the present invention.

We now turn to a description of optical image flow description of the present invention. Starting in the upper right-hand corner of Figure 6, the Lamp and Condensing, Integrating Optics block 624 represents all electrical and optical components that generate and collect light for the rest of the projection system. This block is not fundamentally different from existing light generation systems in current use.

The Color System and 3D Encoder Position A block 626 consists of a rotating color wheel and, depending on the 3D Encoding method chosen, one or more optical components that aid in optically encoding 3D stereoscopic images. The primary responsibility of the Color System is to sequentially filter light emanating from the Lamp optics into three or four separate colors. A secondary purpose of the Color System is to aid in polarization of the light for use in optically encoding 3D images. The 3D Encoder System optically encodes 3D images for transmission to the observer through one of several means including linear polarization, circular polarization, color sequential encoding, and time-sequential encoding. Components of the 3D Encoder system may be physically located in one of several positions, indicated in the figure by Position A 626, Position B 628, and Position C 630. The choice depends on the means used to implement the 3D Encoder System. There are numerous possibilities for the implementation of the Color System and the 3D Encoder System. In some instances the two systems are completely separate and in other instances they are inextricably woven together. The various options and possibilities are discussed in detail later.

The next component in the optical path is the DMD Display 622. The data aspects of this block were discussed previously. Optically the DMD Display 622 consists of the actual DMD display chip and any optics required to reflect light onto and off of the display chip. As previously stated, the DMD display and its optics are not fundamentally different that what is in current use in the projection industry. Virtually any single-chip DMD display system in current use may be utilized in the present invention.

The 3D Encoder Position B block 628 represents a physical location between the DMD Display and the Projection Optics at which portions or all of the 3D Encoder System may be located. Position B is located inside the projector housing.

The Projection Optics block 632 consists of the projection lens, focusing system, zoom system, optical keystone correction (if any) that are used to project the image displayed by the DMD Display block. This system is not fundamentally different than any in use today. The choice of projection optics depends on the DMD Display used and on other cost-performance factors as well as the desired application.

The 3D Encoder Position C 630 block represents a physical location just beyond the Projection Optics at which portions or all of the 3D Encoder System may be located. Position C is located outside the projector housing. The advantage of this configuration is that the Encoding System optics may be configured for removal depending on the desired use and application.

The Display Medium 634 is simply the screen (either front or rear) upon which the image is displayed. If any of the polarization methods for 3D Encoding are used, then the Display Medium 634 must have the ability to reflect or transmit polarized light to the observer.

The 3D Optical Decoder block 636 represents any of the various means that may be used to decode optical 3D image data for presentation to the appropriate eye of the observer. These means typically consist of some type of eyewear that must be worn by the observer. Options include passive linearly polarizing glasses, passive circularly polarizing glasses, active liquid crystal shutter glasses, and active color filter glasses.

## 3D Data Formatter

### 3D Data Formatter Overview

The 3D Data Formatter 618 performs five major functions including input channel selection, stereoscopic demultiplexing, stereoscopic image scaling, scan rate conversion, and stereoscopic

3D format conversion. These functions are realized in the preferred embodiment by the system represented in Figure 7. The 3D Data Formatter block 700 consists of five major components including a Microcontroller Unit 702, a four input two output RGB Input Data Switch/Router System 704, a two input two output RGB Output Data Switch/Router System 706, and two separate Video Processing Units 708 and 710 with associated memory 712 and 714. The most prominent feature of the 3D Data Formatter System is the dual video processor configuration that enables independent image processing for both left- and right-perspective image data. Separate image processors are an important feature and a major distinction between the present invention and other prior art projection systems. The dual-processor configuration provides the highest-image quality available while preventing stereoscopic degradation by keeping left and right image data completely separate.

The 4-to-2 RGB Input Data Switch/Router System 704 is essential a matrix switch for RGBHVC data signals that has the ability to route any input to any or both outputs depending on the 3D Format of the input signal. For instance, in the case where Input Channel A 718 contains both left and right perspective image data, the Input Switch will route Input Channel A 718 to both outputs for further manipulation by the Video Processors. In the case that left and right perspective image data are carried on two separate channels, Channel A 718 and Channel B 720 for example, each input is routed to a single output. In the preferred embodiment this switch is implemented using a high-speed CPLD integrated circuit.

The two Video Processor blocks 708 and 710 and are sophisticated video processing circuits with the ability to perform many useful functions including image resizing, scan rate conversion, color correction, and keystone correction. These processors can control the position in memory of up to four separate consecutive input image data frames and up to four separate output data frames. These features make it possible for each Video Processor to operate on a specific set of image data corresponding to the left or right perspective image. Working in conjunction with the Input Data Switch/Router, virtually any 3D stereoscopic data format may be accommodated. Once the appropriate image data set has been isolated by the input frame controls, each video processor performs the required scaling and image enhancement operations. The Video Processor blocks

708 and 710 also act as dual port memory controls. This means that the output data rate may be independent of the input data rate. Input and output data rates are determined by the horizontal sync, vertical sync and pixel clock signals. The preferred embodiment uses two IP00C711 chips from iChips, Inc. as the Video Processor blocks. Other video processor integrated circuit chips with similar functions and features may also be used. The memory blocks used in the preferred embodiment are 16-megabit SDRAM devices. Sufficient memory is provided to accommodate four complete frame buffers for each Video Processor corresponding to the four frame controls. This configuration provides the maximum control and flexibility required for this system.

The 2-to-2 RGB Output Data Switch/Router block 716 is another RGBHVC digital matrix switch that is capable of routing either input to either output in any possible combination. It is also capable of routing any color data associated with the two input channels to any color location of the two output channels. This feature allows the use of color sequential methods for 3D image encoding. This switch works together with the two Video Processor blocks 708 and 710 to realize all possible 3D data formats that may be used for transmission to the DMD Data Formatter block 700. In the preferred embodiment the output of each Video Processor block 708 and 710 is a 24-bit RGB signal that consists of 8-bits for each color red, green, and blue. To accommodate the color multiplexing feature the Switch 714 is capable of routing any color input to any other color output. Therefore the Switch 714 is actually a 6-input 6-output matrix switch for 8-bit digital signals. In the preferred embodiment this switch is implemented using a high-speed CPLD integrated circuit.

The Microcontroller block 702 performs the setup and control functions of the 3D Data Formatter. It uses an EEPROM memory 710 and 714 to store register settings for each of the Video Processor blocks and data switches. It also interfaces with the user control functions of the projection system and reconfigures the register settings based on user input.

### 3D Data Formatter Input Variants

In the preferred embodiment of the present invention the 3D Data Formatter 700 provides a means and apparatus to accommodate numerous 3D formats from a variety of sources. There many different methods used by 3D content providers to encode 3D image data into video or

computer data formats. Each major 3D format is supported to provide the widest application possible. The major 3D formats supported by the present invention are described below. A representative configuration of the Input Switch 704 and the two Video Processor blocks 708 and 710 are also described.

## Dual Channel 3D Format Input

The Dual Channel 3D Format involves the transmission of left- and right-perspective stereoscopic images on physically separate channels. This format is utilized when two separate video cameras are combined to make a single stereoscopic camera. The present invention accommodates the Dual Channel 3D Format by setting the Input Data Switch to route each input channel to a single separate Video Processor 708 and 710. For instance if the two video sources are present in Input Channel C 722 and Input Channel D 724, then Channel C 722 is routed to Video Processor A 708 and Channel D 724 is routed to Video Processor B 724. Other combinations are, of course, possible. Another major feature of the present invention that stems from the fact that two separate Video Processors are used is that the both channels of the Dual Channel 3D Format may be synchronized independently of one another. This ability stems from the fact that each Video Processor input may be driven independently. Synchronization of the two channels occurs at the output of the Video Processor blocks.

## Single-Channel Frame-Sequential 3D Format Input

Single-Channel 3D Formats seek to multiplex left- and right-perspective stereoscopic images on a single physical channel. There are many different methods employed to accomplish this task. Frame-Sequential 3D Format time-multiplexes the stereo image data based on the Vertical Sync signal of a computer data output. This means that the 3D field changes at every vertical sync pulse. One way in which the present invention demultiplexes this format is to route the selected input channel to both Video Processor blocks. Video Processor A 708 is then set up to process only "even" frames of image data while Video Processor B 710 is set up to process only "odd" frames. The use of "even" and "odd" terms is for convenience only since the RGB port of a computer makes no distinction between even and odd image data frames. However, in the case where the computer supports a VESA standard stereo jack, the even and odd frame definitions may be derived from the Frame ID signal of the port.

### Single-Channel Field-Sequential 3D Format Input

The Field-Sequential 3D Format is very similar to the Frame-Sequential format but applies to video signals instead of computer RGB signals. In this case the selected channel is routed to both Video Processors 708 and 710 as in the previous case. Since many video formats (e.g., NTSC, PAL) distinguish between even and odd fields of each frame of video data, it is possible for the Video Processor blocks 708 and 710 to process only even or odd fields of each video frame.

### Single-Channel Row Interleaved 3D Format Input

The Row-Interleaved 3D format is another RGB computer format that multiplexes stereoscopic image data based on the horizontal sync signal. This results in a row-by-row multiplexing pattern. One of several methods by which the present invention may demultiplex the Row Interleaved 3D format is to route the single input to both Video Processor blocks 708 and 710 and then set the memory control registers 710 and 714 of each Video Processor such that only odd or only even rows are available for processing. Another method is to setup the Input Data Switch 704 to route the selected input channel to both Video Processors 708 and 710 in such a way that rows that are not to be processed are blanked out. For instance if Video Processor A 708 is to operate on information encoded on the even lines, then the Input Data Switch 704 will blank out the odd lines. No matter the method used to demultiplex the row-interleaved format images, each Video Processor 708 and 710 will apply a base scale factor of 2 in the vertical direction to restore the images to full height. Other scale factors may be applied to format the resulting image to the native resolution of the display.

### Single-Channel Over-Under 3D Format Input

The Over-Under 3D Format encodes left and right stereoscopic image data into the top and bottom half of each image frame. For instance one Over-Under method encodes right-perspective data in the top half and left-perspective data in the bottom half of each image frame. One of many ways the present invention may demultiplex Over-Under 3D Format data is to route the selected input to both Video Processor and then set the memory control registers 714 and 710 such that Video Processor A 708 operates on the top half of each frame only and Video Processor B 710 operates on the bottom half of each frame. Other methods are also possible. Finally, each

Video Processor 708 and 710 will apply a base scale factor of 2 in the vertical direction to restore the images to full height. Other scale factors may be applied to format the resulting image to the native resolution of the display.

### Single-Channel Side-By-Side 3D Format Input

The Side-By-Side 3D Format encodes left and right perspective image data on the left and right sides of each image frame. As in the previous cases, one method by which the present invention demultiplexes stereoscopic information in this format is to route the selected channel to both Video Processors. The memory control registers for each Video Processor are then setup such that Video Processor A 708 operates on only the left side of each frame and Video Processor B 710 operates on the right side of each frame. Similar to the previous single-channel formats, each Video Processor will apply a base scale factor of 2 in the horizontal direction to restore the images to full width and maintain the proper aspect ratio. Other scale factors may be applied to format the resulting image to the native resolution of the display.

### Single-Channel Column Interleaved 3D Format Input

The Column Interleaved 3D Format encodes left and right perspective image data on alternating columns of the image frame. This format corresponds to a change in the 3D field for every pixel clock pulse. As in the previous cases the present invention provides several options for demultiplexing this type of 3D format including blanking columns of data on the input pixel clock or by routing the select channel to both Video Processors and then setting memory control registers such that only even or odd columns are processed.

### 3D Data Formatter Output Variants

Just as the 3D Data Formatter is capable of receiving 3D data in many different formats, so too can it transmit processed 3D data in one of many different formats depending on the 3D optical encoding method employed. For any instantiation of the present invention, typically only one of the many 3D optical encoding methods available would be used for the construction of a 3D projection system based on this system. However it is conceivable that there are some cases for which two or more 3D encoding methods may be implemented in a single projection system depending on the application. To provide the widest range of possibilities, the preferred

embodiment of the present invention provides a means and apparatus to implement all of the following 3D data formats for transmission of 3D stereoscopic information from the 3D Data Formatter to the DMD Data Formatter.

- **Frame-Sequential 3D Format:** encodes left and right perspective image data on alternate frames of the output.
- **Over-Under 3D Format:** encodes left and right perspective image data in a single image frame by encoding one perspective image in the top half and the other in the bottom half of each frame.
- **Side-by-Side 3D Format:** encodes left and right perspective image data in a single image frame by encoding one perspective image in the left side and the other in the right side of each frame.
- **Row-Interleaved 3D Format:** encodes left and right perspective image data in a single image frame by encoding one perspective image in the even rows and the other in the odd rows of each frame.
- **Column-Interleaved 3D Format:** encodes left and right perspective image data in a single image frame by encoding one perspective image in the even columns and the other in the odd columns of each frame.
- **Dual-Frame Color Multiplexed Format:** encodes left and right perspective image data in two output image frames by color multiplexing. For example, one possible realization of this format is to encode the red and blue portions of the right image and the green portion of the left image into the first frame and then to encode the red and blue portions of the left image and the green portion of the right image into the second frame.
- **Dual Channel 3D Format:** encodes left and right perspective image data in two physically separated transmission channels.

In addition, each of the 3D data transmissions formats may be used in either an Input Synchronization mode or an Output Synchronization mode. Input Synchronization mode means that data transmission between the 3D Data Formatter 700 illustrated in Figure 7 and the DMD Data Formatter 800 illustrated in Figure 8is synchronized to the external 3D signals that are input

to the projector. The result is that the input signal determines the rate at which 3D images are displayed by the projector. If the data rate of the input signal is too low (typically below 90Hz) there will be a noticeable flickering of the 3D images displayed by the projector. Output Synchronization Mode means that the data transmission between the 3D Data Formatter 700 and the DMD Data Formatter 800 is synchronized independently of the external 3D input signals. The Output Synchronization rate is set internally to the projection system and is set to a level high enough to avoid flicker issues. Both methods are provided by the present invention because there are advantages and disadvantage to both methods. The choice of one method over another will be determined by the intended use and application of the end product.

The entire list of input and output 3D Formats supported by the 3D Data Formatter 700 is presented in Table 1.

**Table 1 - List of Input and Output Formats Supported by the 3D Data Formatter**

| 3D Inputs | 3D Outputs |
|---|---|
| Dual-Channel | Input Synchronized Frame-Sequential |
| Frame-Sequential | Input Synchronized Over-Under |
| Field Sequential | Input Synchronized Side-by-Side |
| Row Interleaved | Input Synchronized Row-Interleaved |
| Over-Under | Input Synchronized Column-Interleaved |
| Side-By-Side | Input Synchronized Dual Frame Color Multiplexed |
| Column-Interleaved | Input Synchronized Dual Channel |
| | Output Synchronized Frame-Sequential |
| | Output Synchronized Over-Under |
| | Output Synchronized Side-by-Side |
| | Output Synchronized Row-Interleaved |
| | Output Synchronized Column-Interleaved |
| | Output Synchronized Dual Frame Color Multiplexed |
| | Output Synchronized Dual Channel |

## DMD Data Formatter

### DMD Data Formatter Overview

The main purpose of the DMD Data Formatter 800 as illustrated in Figure 8 is to convert processed 3D stereoscopic image data in the RGBHVC format into the data format required by the DMD Display chip 622 for proper operation. The DMD Data Formatter 800 also provides

control signals for the Color Management System (including the rotating color wheel filter) and the 3D Encoder/Decoder system 626, 628, and 630. The DMD Data Formatter 800 consists of four major components including a Dual Port Memory Controller802, a DMD Data Converter 804, a Microcontroller 806, and a Color Wheel Controller 808.

The DMD Data Formatter receives input from the 3D Data Formatter in one of the predefined 3D Formats mentioned above. The Dual Port Memory Controller receives RGB data and writes it to memory in a manner set by the Microcontroller. For any instantiation of the present invention only one "write" method is typically used. The Dual Port Memory system (that includes the Dual Port Memory Controller and the memory itself) may consist of a single frame buffer, a dual frame buffer, or a quad frame buffer depending on cost-performance factors. The preferred embodiment implements a dual frame buffer system. There are also three major options for implementation of the timing input data including 60Hz Output Synchronized, 120Hz Output Synchronized, and Variable Rate Input Synchronized. The various options for implementation and their meanings are presented below.

The DMD Data Converter reads data from the Dual Port Memory and reformats it for display. Since the single-chip DMD projection system uses a rotating color wheel to sequentially construct a full color image, the rate at which the DMD Data Converter accesses data in the Dual Port Memory system is significantly faster than the rate at which data is written. The exact manner in which the DMD Data Converter accesses data is determined by the Color Management system and the 3D Encoding system.
The Color Wheel Controller 808 manages the rate at which the color wheel spins based on the rate at which data is being transmitted to the DMD Display 622. The rate of rotation is variable based on the frame rate of the input and whether or not the projector is in Input Synchronized mode or Output Synchronized mode.

The Microcontroller 806 sets the register values for the Dual Port Memory System 802 and 810, the DMD Data Converter 804 and the Color Wheel Controller 808 based on the 3D Format of the

input, the color management mode, and the 3D Encoding method. The Microcontroller 806 also sets the 3D Field Signal used by the 3D Encoding and Decoding Systems.

### DMD Data Formatter Output Methods (3D Display Methods)

Since the present invention is based on using a single-DMD chip, all methods for the display of 3D stereoscopic images involve time-sequential optical encoding. The DMD Display chip 622 is eminently suitable for time-sequential based encoding because of its low latency and super fast switching times. There are identified four major categories of DMD Data Formatter 804 outputs that correspond directly to the 3D Display Method of the entire projection system. These output categories include Input Synchronized Frame Sequential 3D Output, Input Synchronized Color Sequential 3D Output, Output Synchronized Frame Sequential 3D Output, and Output Synchronized Color Sequential 3D Output. Each of these four major output categories is discussed in greater detail below.

### Input Synchronized Frame Sequential 3D

The term Input Synchronized Frame Sequential 3D output means that the 3D Field Rate of the projector (rate of switching between left and right perspective images) is dictated by the input signal frame rate and that each 3D Field consists of a full color left or right perspective image. Based on this description it would seem logical at first glance that the Color Wheel should also rotate at the same rate as the input signal. However, since the color wheel is composed of either three or four distinct color filter types (red, green, blue, and/or white) and since the relative intensity between any two color may be vastly different depending on the image to be displayed, there may be an observable flickering of the projector for input signals whose frame rate is too low. To solve this problem, monoscopic DMD projector manufacturers speed up the rotation of the wheel to as much as twice the rate of the input data frame rate so that the rate of change of the color filters is beyond detection by the human eye. However, since there are limits to the speed at which the color wheel may rotate, the monoscopic projectors may display an input data frame for more than a single rotation of the color wheel. This solution keeps the color change rate high without over taxing the DMD Formatter 800 and color management system. A similar technique must be applied in the present invention for Input Synchronized 3D output.

To illustrate this type of 3D output Figure 9 illustrates two charts 900 demonstrating one method by which the DMD Data Formatter 800 works in conjunction with the DMD Display 622 and a four-segment color wheel to display Input Synchronized Frame Sequential 3D output. The chart also illustrates Input Synchronized Frame-Sequential data transfer from the 3D Data Formatter. The top chart (denoted "DMD Formatter Frame Buffer Plot") 902 represents operation of the Dual Port Memory System of the DMD Data Formatter 800. In this case the Dual Port Memory is implemented using a dual frame buffer. The input line at the top of the frame buffer 904 plot represents the 3D data input to the DMD Data Formatter Dual Port Memory 802 and 810. Gray boxes denote left image data and white boxes denote right image data. The y-axis of the Frame buffer plot represents locations in memory while the x-axis represents time. Dashed lines represent data written to the memory and solid lines represent data read out of the memory. Finally the output line 906 of the DMD Formatter Frame Buffer Plot represents the 3D Format of data transmitted to the DMD display.

The bottom chart ("Image Output Plot") represents the input-output relationship of the combination DMD Display/Color Management System. Rows labeled with the names of colors (e.g., red, white, green, and blue) represent the angular position of the color wheel, ranging from 0° to 360° on the y-axis. The solid black line within this region of the graph represents the position of the color wheel. The x-axis represents elapsed time. The output row represents the actual optical output of the DMD Display/Color Management system combination. L represents left-eye perspective data and R represents right-eye perspective data. Finally the black and white rectangles below the Output row reiterate the sequence of 3D output frames.

Both plots in the figure correspond to each other in time. Starting at time zero we see that data are being read at six times the input frame rate (there are six saw-tooth pulses for every input frame). This represents the transfer of red image data for the first left perspective image to the DMD Display. The result on the output of the projector (Input Output row of the bottom plot) is the red portion of the left-perspective image. Notice that the data are being read from Frame Buffer 1 while new data are being written simultaneously into Frame Buffer 0. During the next frame (a left perspective image), data are being written into Frame Buffer 1 while data are read

for display from Frame Buffer 0. This is the basic operation of the dual frame buffer configuration.

In practice, instead of doubling the rotation rate of the color wheel to prevent color flicker, the color wheel speed is adjusted such that the nearest color boundary coincides with a frame boundary of the input. In the simplified case shown in figure 9, the color wheel is divided into four equal segments of Red, Green, Blue, and White color filters. In practice the white filter may be smaller than the other filters. In the preferred embodiment the color wheel spins at a nominal rate of 120Hz resulting in color transition rate of 4 times 120Hz or 480Hz. Now suppose, for example, that the input frame rate is 75Hz. Dividing the color transition rate by the input frequency and rounding to the nearest integer yields the total number of color time periods per input frame period. In this case we have 480Hz divided by 75Hz equals 6.4. Rounding to the nearest integer results in the number 6. Therefore if we alter the speed of the color wheel such that 6 complete color filter transitions occur for every input data frame then the desired page-flipped output may be achieved with the minimal perceived color flicker. The required color wheel frequency is calculated by multiplying the input frame rate (75Hz) by the computed number of color time periods, 6, and then dividing by the number of colors on the wheel, 4. The result is a color wheel rate of 112.5Hz. Table 2 shows the computed color wheel rotation rates, color transitions per input frame and the color transition rate for various input refresh rates using a four-segment color wheel.

**Table 2 Input Synchronized Frame Sequential 3D Color Wheel Rates for Four-Segment Wheel**

| Input Frame Rate | Color Wheel Rate (Hz) | Color Transitions per Input Frame | Color Transition Rate (Hz) |
|---|---|---|---|
| 60 | 120 | 8 | 480 |
| 72 | 126 | 7 | 504 |
| 75 | 112.5 | 6 | 450 |
| 80 | 120 | 6 | 480 |
| 85 | 127.5 | 6 | 510 |
| 90 | 112.5 | 5 | 450 |
| 100 | 125 | 5 | 500 |
| 110 | 110 | 4 | 440 |
| 120 | 120 | 4 | 480 |

Figure 10 illustrates the same set of charts as described above except that a three-segment color wheel system is used instead of the four-segment color wheel system. Table 3 lists the computed color wheel rotation rates, color transitions per frame and the color transition rates for a three-segment color wheel system using the same input synchronized frame sequential 3D format.

**Table 3 Input Synchronized Frame Sequential 3D Color Wheel Rates for Three-Segment Wheel**

| Input Frame Rate | Color Wheel Rate | Color Transitions per Input Frame | Color Transition Rate (Hz) |
|---|---|---|---|
| 60 | 120 | 6 | 360 |
| 72 | 120 | 5 | 360 |
| 75 | 125 | 5 | 375 |
| 80 | 133.33 | 5 | 400 |
| 85 | 113.33 | 4 | 340 |
| 90 | 120 | 4 | 360 |
| 100 | 133.33 | 4 | 400 |
| 110 | 110 | 3 | 330 |
| 120 | 120 | 3 | 360 |

## Input Synchronized Color Sequential 3D

The term Input Synchronized Color Sequential 3D output means that the 3D Field Rate of the projector (rate of switching between left and right perspective images) is dictated by the input signal frame rate and that each 3D Field consists of one single color of the left or right perspective image. The advantage of this output system is that even though the 3D Field rate is dependent on the input, flicker free operation can now be guaranteed since the switching occurs at the same rate as the color transition rate. As seen in Table 2 this rate varies between 440Hz and 510Hz for the four segment color wheel while Table 3 indicates the rate to range between 330Hz and 400Hz depending on the input frame rate.

There are numerous variations of the DMD Data Formatter and Color Management System that can be used to realize Input Synchronized Color Sequential output. Figure 11 illustrates the output format chart for one such variation. In this case the DMD Data Formatter Dual Port Memory System is realized using a quad frame buffer. Input from the 3D Data Formatter is in the Input Synchronized Frame Sequential Format. As can be seen on the DMD Formatter Frame Buffer Plot, input data frames are written to Frame Buffer 0 through Frame Buffer 3 in order.

This action causes Frame Buffer 0 and 2 to contain only right perspective data and Frame Buffer 2 and 3 to contain only left perspective data. DMD Data Formatter output is read out of the memory in a very different format. In this case data are read from pairs of Frame Buffers as shown. Starting in the middle of the first Left input frame, the output is taken from Frame Buffer 0 followed by Frame Buffer 1. This cycle is repeated for a total of five times after which the output is taken from Frame Buffer 2 followed by Frame Buffer 3. The output is timed so that image data are read at the soonest possible moment after writing without causing a rollover error. In this case the output is delayed by 1.5 input frames. The resulting DMD Data Formatter output switches between left and right perspective image data at every color transition as is shown on the Output line of the Frame Buffer Plot. The lower chart in the figure illustrates the three-segment color wheel plot for Color Sequential Output. The Output line of the lower chart represents the actual output of the projection system. In this case the order is red-right, green-left, blue-right, red-left, green-right, blue-left. Thus over the course of two complete revolutions of the color wheel, two complete full color perspective images are constructed. This version of the Color Sequential Format is called Alternate Color.

Figure 12 illustrates the output format chart for another method available to realize Input Synchronized Color Sequential 3D output. In this case the Color Sequential sub-Format is called "Double Color" since each color is repeated twice, once for the right-perspective image and once for the left perspective image. Another feature of this configuration is that the color wheel is composed of six-segments instead of three. From the lower plot we can see that each color filter is divided into two separate regions corresponding to the left and right perspective images. This color wheel configuration will be discussed in greater detail later. In all other respects this configuration operates as the previous configuration in that a quad frame buffer is used to implement the Dual Port Memory of the DMD Data Formatter. Data transfer into and out of the buffer is identical to that presented previously. It should be noted that there are many other possibilities for implementation.

In addition to the two examples presented there are other possibilities for implementation of the Input Synchronized Color sequential method. These include other methods based on six-segment

and eight-segment color wheels. A complete list of all 3D Display Output formats is located in Table 4.

**Table 4 - 3D Display Formats**

| Num | 3D Display Method | Synchronization Method | Format | Sub-Format | Color Wheel Configuration |
|---|---|---|---|---|---|
| 1 | ISFSPF3 | Input (variable) | Frame Sequential | Page-Flipped | 3-segment |
| 2 | ISFSPF4 | Input (variable) | Frame Sequential | Page-Flipped | 4-segment |
| 3 | ISFSPF6 | Input (variable) | Frame Sequential | Page-Flipped | 6-segment |
| 4 | ISFSPF8 | Input (variable) | Frame Sequential | Page-Flipped | 8-segment |
| 5 | ISCSAC3 | Input (variable) | Color Sequential | Alternate Color | 3-segment |
| 6 | ISCSAC6 | Input (variable) | Color Sequential | Alternate Color | 6-segment |
| 7 | ISCSAC8 | Input (variable) | Color Sequential | Alternate Color | 8-segment |
| 8 | ISCSDC6 | Input (variable) | Color Sequential | Double Color | 6-segment |
| 9 | ISCSDC8 | Input (variable) | Color Sequential | Double Color | 8-segment |
| 10 | OSFSPF3-60 | Output (60Hz) | Frame Sequential | Page-Flipped | 3-segment |
| 11 | OSFSPF4-60 | Output (60Hz) | Frame Sequential | Page-Flipped | 4-segment |
| 12 | OSFSPF6-60 | Output (60Hz) | Frame Sequential | Page-Flipped | 6-segment |
| 13 | OSFSPF8-60 | Output (60Hz) | Frame Sequential | Page-Flipped | 8-segment |
| 14 | OSCSAC3-60 | Output (60Hz) | Color Sequential | Alternate Color | 3-segment |
| 15 | OSCSAC6-60 | Output (60Hz) | Color Sequential | Alternate Color | 6-segment |
| 16 | OCSCAC8-60 | Output (60Hz) | Color Sequential | Alternate Color | 8-segment |
| 17 | OCSCDC6-60 | Output (60Hz) | Color Sequential | Double Color | 6-segment |
| 18 | OCSCDC8-60 | Output (60Hz) | Color Sequential | Double Color | 8-segment |
| 19 | OSFSPF3-120 | Output (120Hz) | Frame Sequential | Page-Flipped | 3-segment |
| 20 | OSFSPF4-120 | Output (120Hz) | Frame Sequential | Page-Flipped | 4-segment |
| 21 | OSFSPF6-120 | Output (120Hz) | Frame Sequential | Page-Flipped | 6-segment |
| 22 | OSFSPF8-120 | Output (120Hz) | Frame Sequential | Page-Flipped | 8-segment |
| 23 | OSCSAC3-120 | Output (120Hz) | Color Sequential | Alternate Color | 3-segment |
| 24 | OSCSAC6-120 | Output (120Hz) | Color | Alternate | 6-segment |

| Num | 3D Display Method | Synchronization Method | Format | Sub-Format | Color Wheel Configuration |
|---|---|---|---|---|---|
| | | | Sequential | Color | |
| 25 | OCSCAC8-120 | Output (120Hz) | Color Sequential | Alternate Color | 8-segment |
| 26 | OCSCDC6-120 | Output (120Hz) | Color Sequential | Double Color | 6-segment |
| 27 | OCSCDC8-120 | Output (120Hz) | Color Sequential | Double Color | 8-segment |

### Output Synchronized Frame Sequential 3D

Output Synchronized Frame Sequential 3D means that the 3D Field Rate of the projector (rate of switching between left and right perspective images) is dictated by the internal color management system and that each 3D Field consists of a full color left or right perspective image. In this case the 3D Field Rate is completely independent and decoupled from the input data frame rate. Output Synchronized 3D Display formats enable flicker free 3D stereoscopic display regardless of the input frame rate. In the preferred embodiment the color wheel rotation rate is set at 120Hz. This rate is the nominal rotation rate for many existing monoscopic projectors (e.g., Plus U2-1080). It provides a 3D Field Rate well above that which is detectable by the human eye.

Since the output display rate of the projector is independent of the input rate for this mode, there exists a freedom of choice for the rate at which data are transmitted from the 3D Data Formatter 700 to the DMD Data Formatter 800. Since the color wheel rotation rate is set at 120Hz, it is convenient to make provisions for a 60Hz and a 120Hz 3D Data Formatter 716 output data rate. Because of its lower performance demands, the 60Hz rate will cost less to implement but may suffer from rollover errors in the dual port memory for some configurations. The 120Hz data rate provides a higher level of performance and visual quality at a higher implementation cost. There are numerous possibilities for implementing the present invention using Output Synchronized Frame Sequential output. A complete list is presented in Table 4. Three examples from this lists are presented below.

Figure 13 illustrates the output format chart for the 60Hz Output Synchronized Frame Sequential 3D method. In this case the DMD Data Formatter Dual Port Memory is configured as a dual frame buffer system. The input data rate is 60Hz and the color wheel rotation rate is 120Hz.

Also a four-segment color wheel system is used to enhance the overall brightness of the image output. As in previous cases input form the 3D Data Formatter 700 is encoded in the frame sequential 3D format. Starting at the left side of the DMD Formatter Frame Buffer Plot, input data is written at address ADDR0 and subsequent addresses as time passes. This configuration causes Frame Buffer 0 to contain only right perspective image data and causes Frame Buffer 1 to contain only left perspective image data. The DMD Data Converter 800 reads data from the dual port memory as indicated by the solid line in the upper plot. Starting at ADDR1 in Frame Buffer 1, data for the red portion of a left perspective image is read followed by white, then green, and then finally blue. The cycle then continues for the next color wheel rotation except that the start address for reading is now set to ADDR0 in Frame Buffer 0. This causes red, white, green, and blue data for a right perspective image to be used for display. A disadvantage of the 60Hz input format can be seen at this point in the fact that the DMD Data Converter 804 reads the right-red data faster than it is being written. This means that at each point in the plot where the solid line (read) crosses the dashed line (write) a transition will occur between the current perspective image frame and the previous perspective image frame. This may result in a noticeable distortion in the displayed image. The lower plot of Figure 13 illustrates the 120Hz frame sequential optical output of the projector.

Figure 14 shows the 120Hz input version of the same configuration. This is the Output Synchronized Frame Sequential 3D output format for 120Hz input. The major difference between this configuration and the previous configuration is that data transfer from the 3D Data Formatter 700 to the DMD Data Formatter 800 takes place at 120Hz. The result is that rollover errors in the Dual Port Memory 810 are eliminated as can be seen by the absence of any intersections between the read and write lines in the upper plot of the figure. All other operation is the same as the 60Hz input example.

To this point each of the examples given has used a frame sequential 3D format to transfer data between the 3D Data Formatter 700 and the DMD Data Formatter 800. Figure 15 illustrates an output format plot in which the over-under 3D format is used instead. This figure represents the Output Synchronized Frame Sequential 3D output configuration with 60Hz Over-Under input.

The only differences between this example and the example of Figure 13 occur in the way data is read out of the Dual Port Memory 810. Since 3D perspective data is written to the Dual Port Memory 810 in the Over-Under format, Frame Buffer 0 and Frame Buffer 1 each contain both left and right perspective image data such that the lower half of each buffer contains (in the example) right-perspective information and the upper half of each buffer contains left-perspective information. To read data for display, an alteration is made in the memory access control registers of the DMD Data Converter so that it only scans one half of the frame buffer. The DMD Data Converter must then scale the image to the full height for display using one of several potential methods including row-blanking (each row of the output image is set to black), row-doubling (each row is repeated to fill up the entire screen), or any other scaling method. The resulting 3D output is the same as in the previous Output Synchronized Frame Sequential Formats. An advantage of the over-under 3D format for DMD Data Formatter input is that it reduces the input-output delay to one half of a frame. A disadvantage is that the effective vertical resolution may be cut in half depending on the 3D format of the input to the projection system.

It should be noted that a similar DMD Data Converter scaling operation would be used in the case where the side-by-side 3D format is used for input to the DMD Data Formatter. For that case scaling methods could include column blanking, column doubling, or any other standard scaling technique.

## Output Synchronized Color Sequential 3D

The Output Synchronized Color Sequential 3D Format is similar to the Output Synchronized Frame Sequential format except that left and right perspective images are encoded by color rather than by frame. Figure 16 illustrates an output format plot of one of many configurations that may be used to realize this format. In this example 3D data input to the DMD Data Formatter 800 are formatted in the Color Multiplexed 3D format at a data rate of 120Hz. The color management system uses a three-segment color wheel for display. The Input line of the DMD Formatter Frame Buffer Plot illustrates how left and right perspective data are multiplexed into the colors of each frame. The first frame in the plot has right image data encoded in the red and blue channels and left image data encoded in the green channel. The next frame inverts the encoding method with the red and blue channels carrying left image data and the green channel carrying

right image data. As in the previous three-segment color wheel examples, the DMD Data Converter 800 reads data from the dual port memory three times for every rotation of the color wheel. Data are read and displayed in the following order: red-left, green-right, blue-left, red-right, green-left, and blue-right. The result is that the 3D Field rate becomes extremely high guaranteeing flicker free operation. There are many other options for implementation of the Output Synchronized Color Sequential 3D format that are listed in Table 4.

### DMD Data Formatter Variations

As is ascertained form the previous description there are many variations of the physical implementation of the DMD Data Formatter 800. The choice depends on the desired performance characteristics and the desired application. Dual Port Memory Configurations including Single Frame Buffer, Dual Frame Buffer, and Quad Frame Buffer implementations. Data input may have variable or fixed rates and may be synchronized internally (with respect to the Color Management System) or externally (with respect to the video or computer input signals).

### 3D Optical Encoding Methods

The present invention provides for various methods to optically encode stereoscopic images for display and transmission to the observer. As was indicated in Figure 6 there are various options for the location and configuration of components used to optically encode 3D images. In order to encode separate left and right perspective images in the same optical channel, the various available properties of light must be exploited. These properties include the speed of light (for time-sequential multiplexing), the visible spectrum (for color-sequential multiplexing), and the polarization properties. The present invention utilizes five major optical components in order to optically encode 3D stereoscopic images using these various properties of light. These components included the color wheel, a cholesteric liquid crystal (CLC) circularly polarizing filter (CPF), a ¼ wave retarder, an linearly polarizing filter (LPF), and an active (electrically switchable) liquid crystal rotator. These components, used in conjunction with the various 3D Display Methods previously discussed may be configured to produce a total of 23 3D optical configurations. The complete list of optical configurations and the components used is found in Table 5. We now turn to a brief discussion of each of the five optical components.

**Table 5 - 3D Optical Configuration Table**

| 3D Optical Config. | Color Wheel Type | CLC CPF[1] | ¼ Wave Plate | LPF[2] | Active Rotator | 3D Display Method | Decode Method [3] | Figure |
|---|---|---|---|---|---|---|---|---|
| A | CW-A | | | | | Frame | ASG | Figure 31 |
| B | CW-A | | | | | Color | ACF | Figure 31 |
| C | CW-A | X | X | | X | Frame | LPG | Figure 32 |
| D | CW-A | | | X | X | Frame | LPG | Figure 33 |
| E | CW-B | | X | | X | Frame | LPG | Figure 34 |
| F | CW-C | | X | | | Frame | LPG | Figure 35 |
| G | CW-C | | X | | | Color | LPG | Figure 35 |
| H | CW-C | | | | | Frame | CPG | Figure 31 |
| I | CW-C | | | | | Color | CPG | Figure 31 |
| J | CW-D | | X | | | Color | LPG | Figure 35 |
| K | CW-D | | | | | Color | CPG | Figure 31 |
| L | CW-E | | X | | | Color | LPG | Figure 35 |
| M | CW-E | | | | | Color | CPG | Figure 31 |
| N | CW-F | | | | | Frame | ASG | Figure 31 |
| O | CW-F | X | X | | X | Frame | LPG | Figure 32 |
| P | CW-F | | | X | X | Frame | LPG | Figure 33 |
| Q | CW-G | | X | | X | Frame | LPG | Figure 34 |
| R | CW-H | | X | | | Frame | LPG | Figure 35 |
| S | CW-H | | | | | Frame | CPG | Figure 31 |
| T | CW-I | | X | | | Color | LPG | Figure 35 |
| U | CW-I | | | | | Color | CPG | Figure 31 |
| V | CW-J | | X | | | Color | LPG | Figure 35 |
| W | CW-J | | | | | Color | CPG | Figure |

[1] Cholesteric Liquid Crystal Circularly Polarizing Filter
[2] Linearly Polarizing Filter
[3] LPG = linearly polarized glasses, CPG = circularly polarized glasses, ASG = Active Shutter Glasses, ACF= Active Color Filter glasses

| 3D Optical Config. | Color Wheel Type | CLC CPF[1] | ¼ Wave Plate | LPF[2] | Active Rotator | 3D Display Method | Decode Method [3] | Figure |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 31 |

**CLC Circularly Polarizing Filter**

Figure 17 illustrates an operational diagram of the CLC circularly polarizing color filter 1700 employed in the present invention. The filter consists of a glass substrate (center)1702, a right handed (RH) CLC coating 1704 (on the left side) and a left-handed (LF) CLC coating 1706. Right-handed CLC reflects right-handed circularly polarized light and left-handed CLC reflects left-handed circularly polarized light. The filter works as follows. White light 1708 from the projection lamp enters from the left of the figure. The RH CLC coating is formulated to reflect right-handed circularly polarized light in all visible and infrared wavelengths 1710. Thus no right-handed circularly polarized light passes through the filter. Eliminating the IR portion of the spectrum helps to reduce heating in optical components farther down in the light path of the projector. To continue, left-handed CP light passes from the RH CLC coating through the glass substrate and falls on the LH CLC Coating. In this example, the LH CLC coating is formulated to reflect left-handed circularly polarized light in the green, blue, and IR wavelengths 1712. Thus only left-handed circularly polarized light in the red wavelengths passes completely through the filter 1714. The result is a red polarizing/color filter that also completely blocks IR radiation.

Other color filters (green, blue, and white) may be implemented by changing the formulation of the LH CLC Coating. Figure 18 illustrates representative drawings of the spectral response of the CLC coatings used to realize a white polarizing filter. The top graph 1802 illustrates the percent reflection response for Filter A (RH CLC Coating). Filter A is used to reflect all RHCP light in the visible and IR wavelengths. The middle graph 1804 illustrates the percent reflection response for Filter B (LH CLC Coating). Since the goal is to realize a white LHCP filter, only the IR portion of the spectrum is reflected. Finally, the bottom graph 1806 shows the percent transmission response for the entire filter assembly. The graph illustrates that filter assembly passes only red, green, and blue LHCP light. This technology is used both for the color wheel and for the stand-alone CLC polarizing filter components.

## Color Wheel

The primary purpose of the color wheel is to aid in generating full color image output. As has been demonstrated by previous examples, there are many possible configurations for the color wheel. In many of these configurations the color wheel is used as both the means to generate full color images and to polarize the light output of the projector for polarization based 3D encoding methods. The CLC color filter technology presented above is used for all of the configurations requiring polarizing filters on the color wheel. There are a total of ten color wheel configurations listed in Table 6. Figure 19 through 28 each illustrate a Color Wheel Type A through J. A graphical representation of each color wheel configuration is presented in the corresponding figure listed in the table. In the CLC Polarization Pattern column of the table, a letter R, G, or B is used to refer to the color output of the polarizing filter, and a number 1 or 2 used to refer to the polarization state of the light output (either right-handed or left-handed circular)

**Table 6 - Color Wheel Configuration Table**

| Color Wheel Type | Colors | CLC Polarization Pattern (P1 & P2) | Color Filters | Reference Figure |
|---|---|---|---|---|
| CW-A | RGB | none | 3 | Figure 19 |
| CW-B | RGB | R1 G1 B1 | 3 | Figure 20 |
| CW-C | RGB | R1 G1 B1 R2 G2 B2 | 6 | Figure 21 |
| CW-D | RGB | R1 R2 G1 G2 B1 B2 | 6 | Figure 22 |
| CW-E | RGB | R1 G2 B1 R2 G1 B2 | 6 | Figure 23 |
| CW-F | RWGB | none | 4 | Figure 24 |
| CW-G | RWGB | R1 W1 G1 B1 | 4 | Figure 25 |
| CW-H | RWGB | R1 W1 G1 B1 R2 W2 G2 B2 | 8 | Figure 26 |
| CW-I | RWGB | R1 R2 W1 W2 G1 G2 B1 B2 | 8 | Figure 27 |
| CW-J | RWGB | R1 W2 G1 B2 W1 R2 B1 G2 | 8 | Figure 28 |

## ¼-Wave Retarder

The ¼-wave retarder is a passive optical element that is used to convert circularly polarized light to linearly polarized light. It may appear at any of three 3D Optical Encoding Positions 626, 628,630 of Figure 6.

## Linearly Polarizing Filter

The linearly polarizing filter (LPF) is another passive optical element that is used to linearly polarize unpolarized light. The LPF is used in conjunction with the active rotator to optically encode left and right perspective images using linearly polarized light.

### Active Liquid Crystal Rotator

The active liquiwd crystal rotator (ALCR) is used to switch the light output between to orthogonal linearly polarized states. Figure 29 illustrates the operation of the ALCR in the OFF state 2900. In this case vertically polarized light 2902 enters from the left side of the figure and as converted to horizontally polarized light 2904 as it passes through the ALCR. In effect the filter rotates the polarization angle of the input light by 90°. Figure 30 illustrates the operation of the ALCR in the ON state (electric field is applied) 3000. In this case the polarization angle of the input light 3002 is left unchanged 3004.

### Optical Encoding System Configurations

A complete list of the feasible configurations A-W for 3D optical encoding using the five components listed above is presented in Table 5. The table also lists the figures. Figures 31 through 35 are associated with each configuration. The table indicates the color wheel type used, the usage of a separate CLC polarizer, the usage of a ¼-wave retarder, the usage of a linear polarizer, and the usage of an active rotator by the placement of an "X" in the appropriate column. The table also indicates the 3D Display method required for proper operation of the encoding method and finally refers to the 3D Decoding method required for proper stereo viewing.

### 3D Optical Decoding Methods

The final component category of the present invention is the 3D Optical Decoding system. This system optically decodes left and right perspective images for presentation to the observer. The system is physically located near the observer. In fact each of the four methods for implementation take the form of eyewear that is worn by the observer. Implementations other than eyewear may be realized depending on the situation and application. The four 3D Optical Decoding methods of the present invention include: passive linearly polarized glasses, passive circularly polarized glasses, active liquid crystal shutter glasses, and active color filter glasses. The choice of which method to use depends on the application and price-performance factors. For instance the least expensive method uses linearly polarized glasses and the most expensive method is the active color filter glasses. Active shutter glasses are likely to have the best

performance while circularly polarized glasses are likely to have the worst performance. Each method is present in more detail below.

### Passive Linearly and Circularly Polarized Glasses

Passive polarized glasses 3600 consist of two polarizing filters, one for each eye, which block selected polarization states. One 3602 filter blocks light in the P1 polarization state and the other filter 3604 blocks light in the P2 polarization state as shown in Figure 36. The figure holds for either linear or circular polarizing filters. 3D eyewear is ubiquitous in it usage with 3D projection systems.

### Active Liquid Crystal Shutter Glasses

The operation of a typical liquid crystal shutter 3700 is demonstrated in Figure 37 below. Typical LC shutters employ an active liquid crystal element sandwiched between two crossed polarizers as shown in the figure. The first linear polarizer, labeled P1 3702, polarizes light entering the shutter from the left 3704. The active shutter element 3706 has two possible states. It either passes the polarized light without changing the polarization orientation or it rotates the polarization angle to that of the output polarizer P2. If the active element passes the light without changing the polarization state the output polarizer prevents light from exiting the shutter since its polarization angle is orthogonal to that of the light exiting the active element. However, if the active element switches the polarization angle of the light to that of the output, the output polarizer will allow the light to pass out of the shutter

The use of liquid crystal shutter glasses 3800 for 3D stereoscopic viewing is demonstrated Figure 38. A sequence of images that alternate between the left and right view perspective is displayed on a viewing screen. Two shutters, which serve as the primary optical components of the shutter glasses, are opened and closed in such a way that left eye shutter is open only when the left eye image is displayed on the view screen and the right eye shutter is open only when the right eye image is displayed. When a shutter is closed ideally all light is blocked from passing through the shutter element as shown in the figure. When the shutter is opened, the shutter is transparent allowing the underlying eye to see the intended image. The figure illustrates the transition from the left eye view to the right eye view from left to right with the left eye cycle on the left of the

figure and the right eye cycle on the right of the figure. In the figure time increases from left to right.

### Active Color Filter Glasses

Active color filter glasses are very similar to active shutter glasses except that the second polarizer is replaced with a special polarization selective color filter. ColorLink, Inc. makes a color filter material that transmits green light when the input light is linearly polarized in the P1 state and transmits magenta light (the combination of red and blue) when the input is P2 linearly polarized. Figure 39 illustrates a functional diagram for a single switchable color filter lens 3900. As in the shutter glass example above, unpolarized light 3902 on the left of figure 39 passes through polarizer P1. If the active LC cell is OFF the polarization angle is rotated by 90° to the P2 state. Since the polarized light is P2 polarized the color filter 3908 passes only the red and blue (magenta) wavelengths and blocks the green. When the LC cell 3906 is ON the output polarization state becomes P1 and the color filter passes green and blocks red and blue. Shutter glasses based on this color filter design use two filter assemblies with opposite states so that when one filter transmits green the other filter transmits magenta and vice versa.

### Conversion from 2D to 3D

A method of converting a digital micro-mirror device based 2D projection system to a digital micro-mirror device based 3 D projection system includes installing a 3D data formater; installing a digital micro mirror device data formatter; optionally replacing an existing color wheel with a color wheel formatted for 3D; and installing 3D optical encoder system in one of three positions in an optical path of said system.

The 3D data formater includes a 4:2 RGB Input Data Switch/router coupled to two video processors each coupled to a memory system; a microcontroller coupled to said 4:2 RGB input data switch/router, to said video processors and to a 2:2 RGB output data switch router and an output of each video processor coupled to said 2:2 RGB output data switch router.

The digital micro-mirror device data formatter includes a dual port memory controller coupled to a memory, a digital micro-mirror data converter and a microcontroller; the digital micro-mirror data converter provides output digital micro-mirror device data; and the microcontroller provides control signals to said dual-port memory controller, the digital memory device data converter and a color wheel controller as well as 3D field signal.

The optional color wheel includes: 1) a three segment color wheel comprising a red; green; and blue filter wherein said filters are placed in a rotation direction of said wheel; 2) a three segment wheel further comprising a red circular polarization filter; a green circular polarization filter; and a blue circular polarization filter; 3) a six segment wheel further comprising a red circular polarization filter with a first polarization state; a green circular polarization filter with a first polarization state; a blue circular polarization filter with a first polarization state and a blue circular polarization filter; a red circular polarization filter with a second polarization state; a green circular polarization filter with a second polarization state; and a blue circular polarization filter with a second polarization state, wherein said filters are placed in a rotation direction of said wheel; 4) a six segment wheel further comprising a red circular polarization filter with a first polarization state; a red circular polarization filter with a second polarization state; a green circular polarization filter with a first polarization state; a green circular polarization filter with a second polarization state; a blue circular polarization filter with a first polarization state; and a blue circular polarization filter with a second polarization state, wherein said filters are placed in a rotation direction of said wheel; 5) a six segment wheel further having a red circular polarization filter with a first polarization state; a green circular polarization filter having a second polarization state; a blue circular polarization filter having a first polarization state; a red circular polarization filter having a second polarization state; a green circular polarization filter having a first polarization state; and a blue circular polarization filter having a second polarization state, wherein said filters are placed in a rotation direction of said wheel; 6) a four segment color wheel having a red filter; a white filter; a green filter; and a blue filter, wherein said filters are placed in a rotation direction of said wheel; 7) a four segment wheel further having a first red circular polarization filter having a first polarization state; a first white circular polarization filter; a first green circular polarization filter; a first blue circular polarization filter, wherein all filters have a same polarization state and are positioned in a rotation direction of said wheel. 8) an eight segment wheel further comprising a first red circular polarization filter having a first polarization state; a first white circular polarization filter having a first polarization state; a first green circular polarization filter having a first polarization state; a first blue circular polarization filter having a first polarization state; a second red circular polarization filter having a second polarization state; a second white circular polarization filter

having a second polarization state; a second green circular polarization filter having a second polarization state; a second blue circular polarization filter having a second polarization state, wherein said filters are positioned in a rotation direction of said wheel; 9) an eight segment wheel further comprising a first red circular polarization filter having a first polarization state; a second red circular polarization filter having a second polarization state; a first white circular polarization filter having a first polarization state; a second white circular polarization filter having a second polarization state; a first green circular polarization filter having a first polarization state; a second green circular polarization filter having a second polarization state; a first blue circular polarization filter having a first polarization state; a second blue circular polarization filter having a second polarization state, wherein said filters are placed in a rotation direction of said wheel; 10) an eight segment wheel further comprising a first red circular polarization filter having a first polarization state; a first white circular polarization filter having a second polarization state; a first green circular polarization filter having a first polarization state; a first white circular polarization filter having a first polarization state; a second white circular polarization filter having a first polarization state; a second red circular polarization filter having a second polarization state; a second blue circular polarization filter having a first polarization state; a second green circular polarization filter having a second polarization state, wherein said filters are placed in a rotation direction of said wheel.

A method of converting a 4 color wheel system into a 3 color wheel system includes in addtion to the above blocking the light output during the white transition of the 4 color wheel. Methods for blocking include mechanical occlusion of the white filter on the color wheel, the use of an internal or external LC shutter system that is synchronized to block light during the white filter output, the use of an internal or external mechanical shutter that is synchronized to block light during the white filter output.

The implementations of 3D systems into DMD projection systems as illustrated are merely exemplary. It is understood that other implementations will readily occur to persons with ordinary skill in the art. All such implantations and variations are deemed to be within the scope and spirit of the present invention as defined by the accompanying claims.

What is Claimed Is:

1. A digital micro-mirror device based 3D projection system comprising:

a 3D data system coupling 3D images to an electrical input of a color system and digital micro-mirror display device; and

a 3D optical system coupling an output of a light source through an optical path comprising said digital micro-mirror display device, a 3D optical encoder and projector optics to a display medium; wherein said 3D projection system displays 3D images onto said display medium.

2. The system of claim 1 wherein said data system comprises:

a least one front end processing portion;

a 3D data formatter;

a digital micro-mirror device data formatter; and

a digital micro-mirror display device,

wherein said 3D data system provides color system control signals to a color system and 3D encoder as well as digital micro-mirror display data to said digital micro-mirror display device.

3. The system of claim 2 wherein said front end processing comprises:

analog to digital conversion of the input data;

luminance to chroma separation of said data;

chroma demodulation of said data;

color space conversion of said data;

a de-gamma process of said data; and

error diffusion of said data.

4. The system of claim 2 wherein said 3D data formatter comprises;

a 4:2 RGB Input Data Switch/router coupled to two video processors each coupled to a memory system;

a microcontroller coupled to said 4:2 RGB input data switch/router, to said video processors and to a 2:2 RGB output data switch router and

an output of each video processor coupled to said 2:2 RGB output data switch router.

5. The system of claim 2 wherein said digital micro-mirror device data formatter comprises:

a dual port memory controller coupled to a memory, a digital micro-mirror data converter and a microcontroller;

said digital micro-mirror data converter provides output digital micro-mirror device data;

said microcontroller provides control signals to said dual-port memory controller, said digital memory device data converter and a color wheel controller as well as 3D field signal.

6. The system of claim 2 wherein said digital micro-mirror display device comprises a micro electro-mechanical system having an array of bi-stable mirrors fabricated over a CMOS memory substrate wherein said display device modulates an inputted light with a movement of said mirrors commanded by said digital micro-mirror device data.

7. The system of claim 1 wherein said optical system comprises:

a subsystem comprising a lamp, a condensing system, integrating optics coupling light to a color system;

said color system selectively transmitting light of at least three primary colors;

a digital micro-mirror display device selectively transmitting a plurality of pixels of selected color information;

a 3D encoder system placed in one of three positions in the light path of said 3D projector system;

a projection optics system that transmits said 3D image on to a display medium; and

a 3D optical decoder system selecting a left image and a right image from the 3D image for use by an observer using said 3D optical decoder.

8. The optical system of claim 7 wherein said color system comprises a color wheel with color filters.

9. The optical system of claim 8 wherein said color wheel has three filters, a red filer, a green filter and a blue filter, wherein said filters are placed in a rotation direction of said wheel.

10. The optical system of claim 8 wherein said optional color wheel comprises:

a three segment wheel further comprising a red circular polarization filter with a first polarization state;

a green circular polarization filter with a first polarization state;

a blue circular polarization filter with a first polarization state; wherein said filters are placed in a rotation direction of said wheel.

11. The optical system of claim 8 wherein said optional color wheel comprises:

a six segment wheel further comprising a red circular polarization filter with a first polarization state;

a red circular polarization filter with a first polarization state;

a green circular polarization filter with a first polarization state;

a blue circular polarization filter with a first polarization state;

a red circular polarization filter with a second polarization state;

a green circular polarization filter with a second polarization state; and

a blue circular polarization filter with a second polarization state, wherein said filters are placed in a rotation direction of said wheel.

12. The optical system of claim 8 wherein said optional color wheel comprises:

a six-segment wheel further comprising a red circular polarization filter with a first polarization state;

a red circular polarization filter with a second polarization state;

a green circular polarization filter with a first polarization state;

a green circular polarization filter with a second polarization state;

a blue circular polarization filter with a first polarization state; and

a blue circular polarization filter with a second polarization state, wherein said filters are placed in a rotation direction of said wheel.

13. The optical system of claim 8 wherein said color wheel comprises:

a six-segment wheel further comprising a red circular polarization filter with a first polarization state;

a green circular polarization filter having a second polarization state;

a blue circular polarization filter having a first polarization state;

a red circular polarization filter having a second polarization state;

a green circular polarization filter having a first polarization state; and

a blue circular polarization filter having a second polarization state, wherein said filters are placed in a rotation direction of said wheel.

14. The optical system of claim 8 wherein said color wheel comprises:

a four segment color wheel comprising:

a red filter;

a white filter;

a green filter; and

a blue filter, wherein said filters are placed in a rotation direction of said wheel.

15. The optical system of claim 8 wherein said color wheel comprises:

a four-segment wheel further comprising a first red circular polarization filter having a first polarization state;

a first white circular polarization filter;

a first green circular polarization filter;

a first blue circular polarization filter, wherein all filters have a same polarization state and are positioned in a rotation direction of said wheel.

16. The optical system of claim 8 wherein said optional color wheel comprises:

an eight-segment wheel further comprising a first red circular polarization filter having a first polarization state;

a first white circular polarization filter having a first polarization state;

a first green circular polarization filter having a first polarization state;

a first blue circular polarization filter having a first polarization state;

a second red circular polarization filter having a second polarization state;

a second white circular polarization filter having a second polarization state;

a second green circular polarization filter having a second polarization state;

a second blue circular polarization filter having a second polarization state, wherein said filters are positioned in a rotation direction of said wheel.

17. The method of claim 8 wherein said color wheel comprises:

an eight-segment wheel further comprising a first red circular polarization filter having a first polarization state;

a second red circular polarization filter having a second polarization state;

a first white circular polarization filter having a first polarization state;

a second white circular polarization filter having a second polarization state;

a first green circular polarization filter having a first polarization state;

a second green circular polarization filter having a second polarization state;

a first blue circular polarization filter having a first polarization state;

a second blue circular polarization filter having a second polarization state, wherein said filters are placed in a rotation direction of said wheel.

18. The method of claim 8 wherein said optional color wheel comprises:

an eight-segment wheel further comprising a first red circular polarization filter having a first polarization state;

a first white circular polarization filter having a second polarization state;

a first green circular polarization filter having a first polarization state;

a first white circular polarization filter having a first polarization state;

a second white circular polarization filter having a first polarization state;

a second red circular polarization filter having a second polarization state;

a second blue circular polarization filter having a first polarization state;

a second green circular polarization filter having a second polarization state, wherein said filters are placed in a rotation direction of said wheel.

19. The optical system of claim 7 wherein said digital micro-mirror display device comprises a micro electro-mechanical system having an array of bi-stable mirrors fabricated over a CMOS memory substrate wherein said display device modulates an inputted light with a movement of said mirrors commanded by a digital micro-mirror device data.

20. The optical system of claim 7 wherein a first 3D encoder location is located between said integrating optics and said digital micro-mirror display device and comprises means for encoding 3D images for transmissions said means selected from the group consisting of linear polarization, circular polarization, color sequential encoding, and time-sequential encoding.

21. The optical system of claim 7 wherein a second 3D encoder location is located between said digital micro-mirror display device and said projector optics and comprises means for encoding 3D images for transmissions said means selected from the group consisting of linear polarization, circular polarization, color sequential encoding, and time-sequential encoding.

22. The optical system of claim 7 wherein a third 3D encoder location is located between said projector optics and display medium either physically within said projector or mounted externally to said projector comprises means for encoding 3D images for transmissions said means selected

from the group consisting of linear polarization, circular polarization, color sequential encoding, and time-sequential encoding.

23. The optical system of claim 7 wherein said 3D optical decoder comprises eyeglasses.

24. The optical decoder of claim 15 comprising eyeglasses with active elements.

25. The optical decoder of claim 15 comprising eyeglasses with passive elements.

26. The system of claim 1 wherein said electrical input comprises dual-channel 3D input.

27 The system of claim 1 wherein said electrical input comprises a frame sequential 3D input.

28. The system of claim 1 wherein said electrical input comprises a field sequential 3D input.

29. The system of claim 1 wherein said electrical input comprises a row interleaved 3D input.

30. The system of claim 1 wherein said electrical input comprises over-under 3D input.

31. The system of claim 1 wherein said electrical input comprises a side-by-side 3D input.

32. The system of claim 1 wherein said electrical input comprises a column-interleaved 3D input.

33. The system of claim 1 wherein said 3D output comprises an input synchronized frame sequential 3D signal.

34. The system of claim 4 wherein said 3D output comprises an input synchronized over-under 3D signal.

35. The system of claim 4 wherein said 3D output comprises an input synchronized side-by-side 3D signal.

36. The system of claim 4 wherein said 3D output comprises an input synchronized row-interleaved 3D signal.

37. The system of claim 4 wherein said 3D output comprises an input synchronized column-interleaved 3D signal.

38. The system of claim 4 wherein said 3D output comprises an input synchronized dual-channel 3D signal.

39. The system of claim 4 wherein said 3D output comprises an input synchronized dual-frame color multiplexed 3D signal.

40. The system of claim 4 wherein said 3D output comprises an output synchronized frame sequential 3D signal.

41. The system of claim 4 wherein said 3D output comprises an output synchronized over-under 3D signal.

42. The system of claim 4 wherein said 3D output comprises an output synchronized side-by-side 3D signal.

43. The system of claim 4 wherein said 3D output comprises an output synchronized row-interleaved 3D signal.

44. The system of claim 4 wherein said 3D output comprises an output synchronized column-interleaved 3D signal.

45. The system of claim 4 wherein said 3D output comprises an output synchronized dual-frame color multiplexed 3D signal.

46. The system of claim 4 wherein said 3D output comprises an input synchronized dual-channel 3D signal.

47. The system of claim 1 wherein an input synchronization method produces a frame sequential format with a page page-flipped sub-format and uses a 3-segment color wheel.

48. The system of claim 1 wherein an input synchronization method produces a frame sequential format with a page-flipped sub-format and uses a 4-segment color wheel.

49. The system of claim 1 wherein an input synchronization method produces a frame sequential format with a page-flipped sub-format and uses a 6-segment color wheel.

50. The system of claim 1 wherein an input synchronization method produces a frame sequential format with a page-flipped sub-format and uses an 8-segment color wheel.

51. The system of claim 1 wherein an input synchronization method produces a color sequential format with an alternate color sub-format and uses a 3-segment color wheel.

52. The system of claim 1 wherein an input synchronization method produces a color sequential format with an alternate color sub-format and uses a 6-segment color wheel.

53. The system of claim 1 wherein an input synchronization method produces a color sequential format with an alternate color sub-format and uses an 8-segment color wheel.

54. The system of claim 1 wherein an input synchronization method produces a color sequential format with a double color sub-format and uses a 6-segment color wheel.

55. The system of claim 1 wherein an input synchronization method produces a color sequential format with a double color sub-format and uses an 8-segment color wheel.

56. The system of claim 1 wherein a 60 Hz output synchronization method produces a frame sequential format with a page page-flipped sub-format and uses a 3-segment color wheel.

57. The system of claim 1 wherein a 60 Hz output synchronization method produces a frame sequential format with a page-flipped sub-format and uses a 4-segment color wheel.
58. The system of claim 1 wherein a 60 Hz output synchronization method produces a frame sequential format with a page-flipped sub-format and uses a 6-segment color wheel.
59. The system of claim 1 wherein a 60 Hz output synchronization method produces a frame sequential format with a page-flipped sub-format and uses an 8-segment color wheel.
60. The system of claim 1 wherein a 60 Hz output synchronization method produces a color sequential format with an alternate color sub-format and uses a 3-segment color wheel.
61. The system of claim 1 wherein a 60 Hz output synchronization method produces a color sequential format with an alternate color sub-format and uses a 6-segment color wheel.
62. The system of claim 1 wherein a 60 Hz output synchronization method produces a color sequential format with an alternate color sub-format and uses an 8-segment color wheel.
63. The system of claim 1 wherein a 60 Hz output synchronization method produces a color sequential format with a double color sub-format and uses a 6-segment color wheel.
64. The system of claim 1 wherein a 60 Hz output synchronization method produces a color sequential format with a double color sub-format and uses an 8-segment color wheel.
65. The system of claim 1 wherein a 120 Hz output synchronization method produces a frame sequential format with a page page-flipped sub-format and uses a 3-segment color wheel.
66. The system of claim 1 wherein a 120 Hz output synchronization method produces a frame sequential format with a page-flipped sub-format and uses a 4-segment color wheel.
67. The system of claim 1 wherein a 120 Hz output synchronization method produces a frame sequential format with a page-flipped sub-format and uses a 6-segment color wheel.
68. The system of claim 1 wherein a 120 Hz output synchronization method produces a frame sequential format with a page-flipped sub-format and uses an 8-segment color wheel.
69. The system of claim 1 wherein a 120 Hz output synchronization method produces a color sequential format with an alternate color sub-format and uses a 3-segment color wheel.
70. The system of claim 1 wherein a 120 Hz output synchronization method produces a color sequential format with an alternate color sub-format and uses a 6-segment color wheel.
71. The system of claim 1 wherein a 120 Hz output synchronization method produces a color sequential format with an alternate color sub-format and uses an 8-segment color wheel.

72. The system of claim 1 wherein a 120 Hz output synchronization method produces a color sequential format with a double color sub-format and uses a 6-segment color wheel.

73. The system of claim 1 wherein a 120 Hz output synchronization method produces a color sequential format with a double color sub-format and uses an 8-segment color wheel.

74. A method of conversion of a digital micro-mirror device based 2D projection system to a digital micro-mirror device based 3 D projection system comprising;

installing a 3D data formatter;

installing a digital micro mirror device data formatter;

optionally replacing an existing color wheel with a color wheel formatted for 3D; and

installing 3D optical encoder system in one of three positions in an optical path of said system.

75. The method of claim 74 wherein said 3D data formatter comprises:

a 4:2 RGB Input Data Switch/router coupled to two video processors each coupled to a memory system;

a microcontroller coupled to said 4:2 RGB input data switch/router, to said video processors and to a 2:2 RGB output data switch router and

an output of each video processor coupled to said 2:2 RGB output data switch router.

76. The method of claim 75 wherein said 2:2 RGB output data switch router comprises a 6:6 8 bit data switch router.

77. The method of claim 74 wherein said digital micro-mirror device data formatter comprises:

a dual port memory controller coupled to a memory, a digital micro-mirror data converter and a microcontroller;

said digital micro-mirror data converter provides output digital micro-mirror device data; and

said microcontroller provides control signals to said dual-port memory controller, said digital memory device data converter and a color wheel controller as well as 3D field signal.

78. The method of claim 74 wherein said optional color wheel comprises:

a three segment color wheel comprising a red; green; and blue filter wherein said filters are placed in a rotation direction of said wheel.

79. The method of claim 74 wherein said optional color wheel comprises:

a three-segment wheel further comprising a red circular polarization filter;

a green circular polarization filter; and

a blue circular polarization filter.

80. The method of claim 74 wherein said optional color wheel comprises:

a six-segment wheel further comprising a red circular polarization filter with a first polarization state;

a green circular polarization filter with a first polarization state;

a blue circular polarization filter with a first polarization state and a blue circular polarization filter;

a red circular polarization filter with a second polarization state;

a green circular polarization filter with a second polarization state; and

a blue circular polarization filter with a second polarization state, wherein said filters are placed in a rotation direction of said wheel.

81. The method of claim 74 wherein said optional color wheel comprises:

a six-segment wheel further comprising a red circular polarization filter with a first polarization state;

a red circular polarization filter with a second polarization state;

a green circular polarization filter with a first polarization state;

a green circular polarization filter with a second polarization state;

a blue circular polarization filter with a first polarization state; and

a blue circular polarization filter with a second polarization state, wherein said filters are placed in a rotation direction of said wheel.

82. The method of claim 74 wherein said optional color wheel comprises:

a six-segment wheel further comprising a red circular polarization filter with a first polarization state;

a green circular polarization filter having a second polarization state;

a blue circular polarization filter having a first polarization state;

a red circular polarization filter having a second polarization state;

a green circular polarization filter having a first polarization state; and

a blue circular polarization filter having a second polarization state, wherein said filters are placed in a rotation direction of said wheel.

83. The method of claim 74 wherein said optional color wheel comprises:

a four segment color wheel comprising:

a red filter;

a white filter;

a green filter; and

a blue filter, wherein said filters are placed in a rotation direction of said wheel.

84. The method of claim 74 wherein said optional color wheel comprises:

a four-segment wheel further comprising a first red circular polarization filter having a first polarization state;

a first white circular polarization filter;

a first green circular polarization filter;

a first blue circular polarization filter, wherein all filters have a same polarization state and are positioned in a rotation direction of said wheel.

85. The method of claim 76 wherein said optional color wheel comprises:

an eight-segment wheel further comprising a first red circular polarization filter having a first polarization state;

a first white circular polarization filter having a first polarization state;

a first green circular polarization filter having a first polarization state;

a first blue circular polarization filter having a first polarization state;

a second red circular polarization filter having a second polarization state;

a second white circular polarization filter having a second polarization state;

a second green circular polarization filter having a second polarization state;

a second blue circular polarization filter having a second polarization state, wherein said filters are positioned in a rotation direction of said wheel.

86. The method of claim 74 wherein said optional color wheel comprises:

an eight-segment wheel further comprising a first red circular polarization filter having a first polarization state;

a second red circular polarization filter having a second polarization state;

a first white circular polarization filter having a first polarization state;

a second white circular polarization filter having a second polarization state;

a first green circular polarization filter having a first polarization state;

a second green circular polarization filter having a second polarization state;

a first blue circular polarization filter having a first polarization state;

a second blue circular polarization filter having a second polarization state, wherein said filters are placed in a rotation direction of said wheel.

87. The method of claim 74 wherein said optional color wheel comprises:

an eight-segment wheel further comprising a first red circular polarization filter having a first polarization state;

a first white circular polarization filter having a second polarization state;

a first green circular polarization filter having a first polarization state;

a first white circular polarization filter having a first polarization state;

a second white circular polarization filter having a first polarization state;

a second red circular polarization filter having a second polarization state;

a second blue circular polarization filter having a first polarization state;

a second green circular polarization filter having a second polarization state, wherein said filters are placed in a rotation direction of said wheel.

88. A method of converting a 4 color wheel system into a 3 color wheel system comprises claims 74 – 87 and further comprises blocking a light output during the white transition of a 4 color wheel.

89. The method of claim 88 further comprising including a mechanical occlusion of said white filter on said color wheel.

90. The method of claim 88 further comprising adding an internal or external LC shutter system that is synchronized to block light during said white filter output.

91. The method of claim 88 further comprising using an internal or external mechanical shutter that is synchronized to block light during said white filter output.

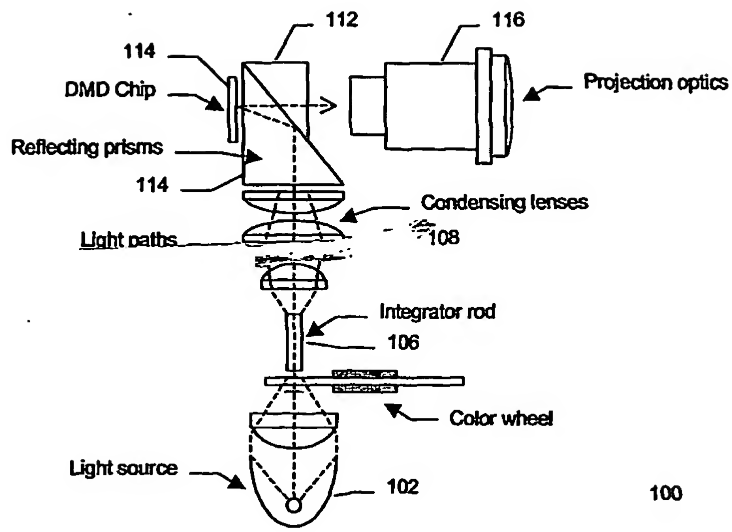



**Figure 1 - Prior Art Single-Chip DMD Projection System – Example 1**

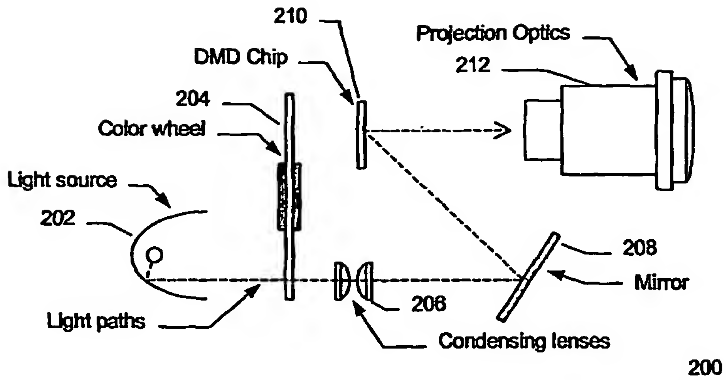



**Figure 2 - Prior Art Single-Chip DMD Projection System – Example 2**

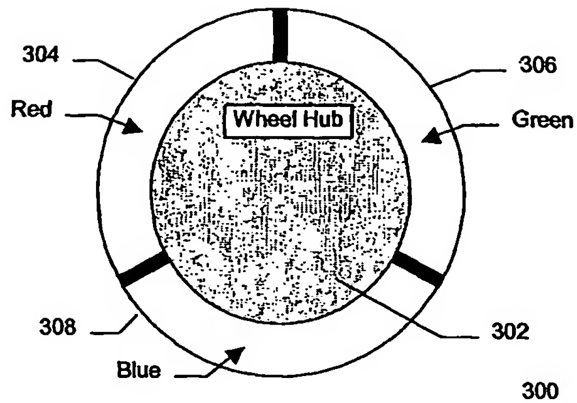



**Figure 3 - Three-Segment Color Wheel for Single Chip DMD Projection Systems**

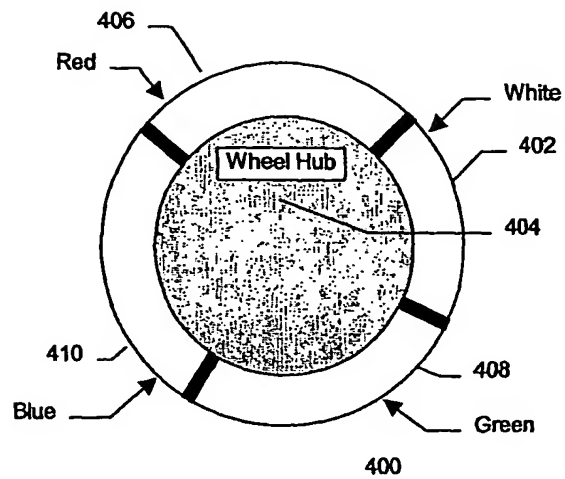



**Figure 4 - Four-Segment Color Wheel for Single Chip DMD Projection Systems**

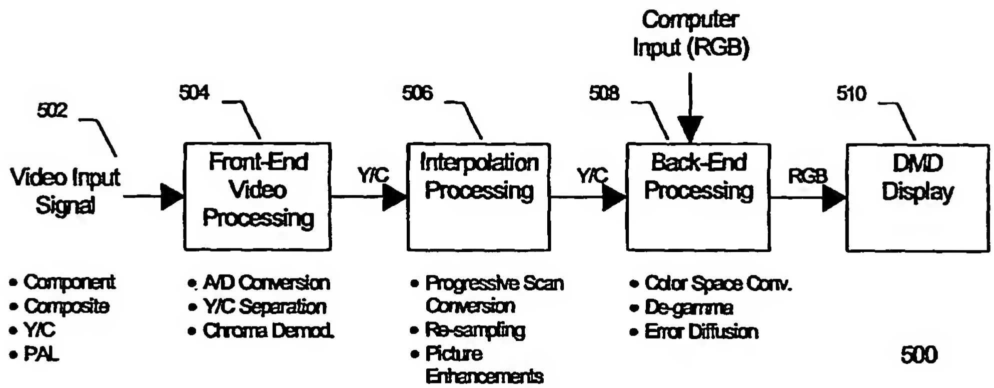



**Figure 5 - Prior-Art DMD Projector Video Processing Block Diagram for Single-Chip DLP Projector**

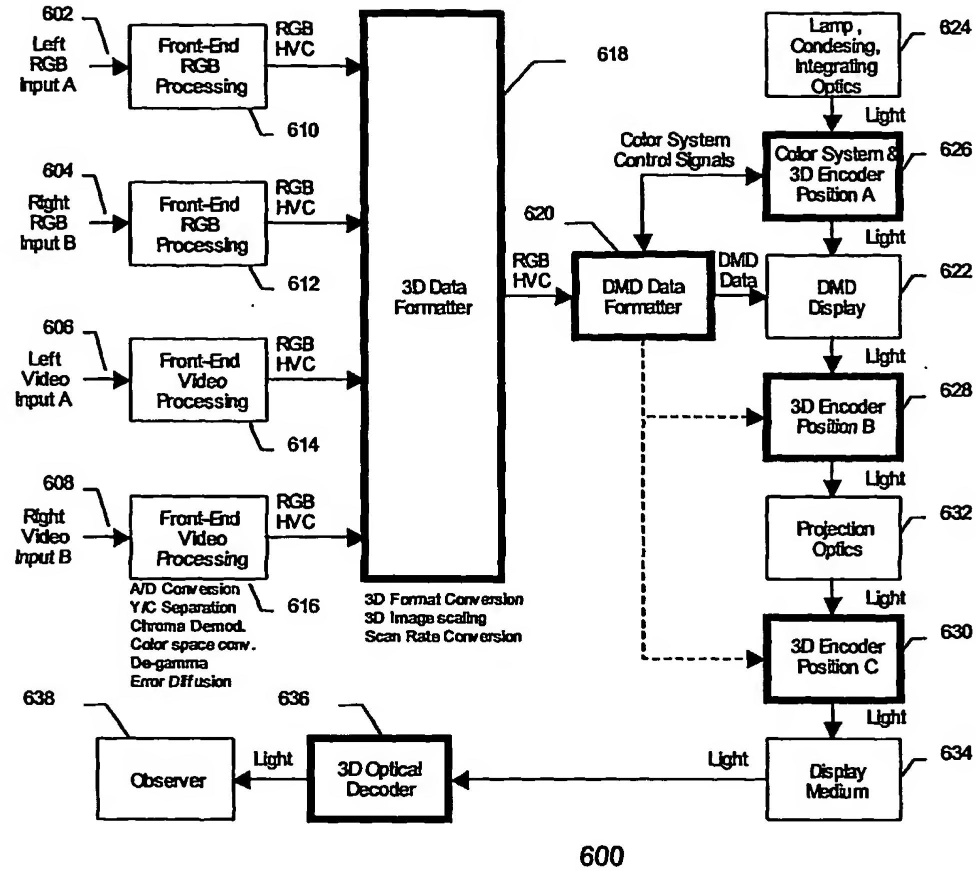



**Figure 6 - Signal Flow and Optics Block Diagram for DMD Based 3D Projection System**

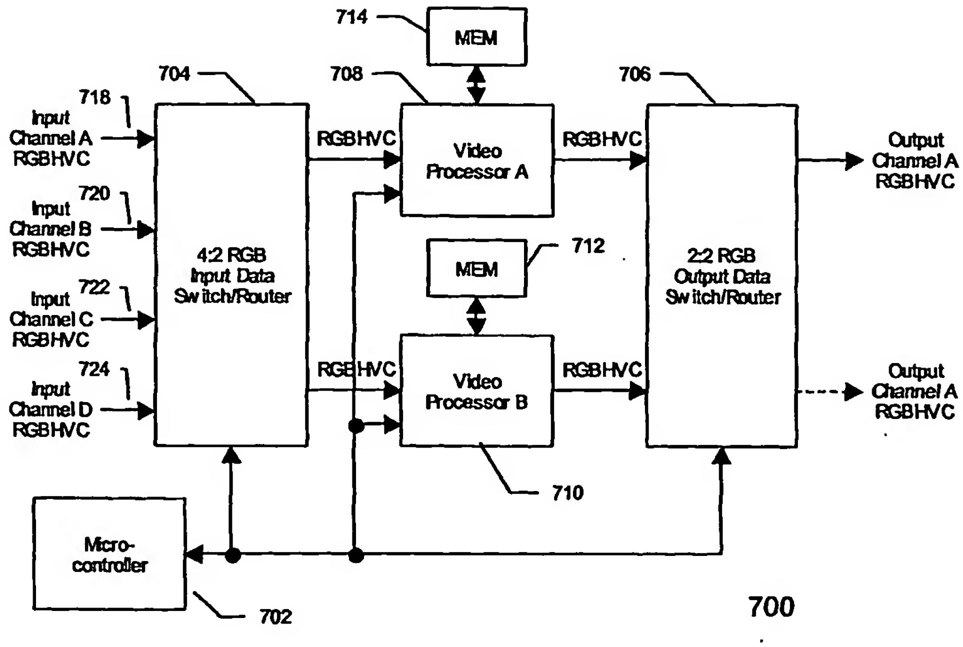
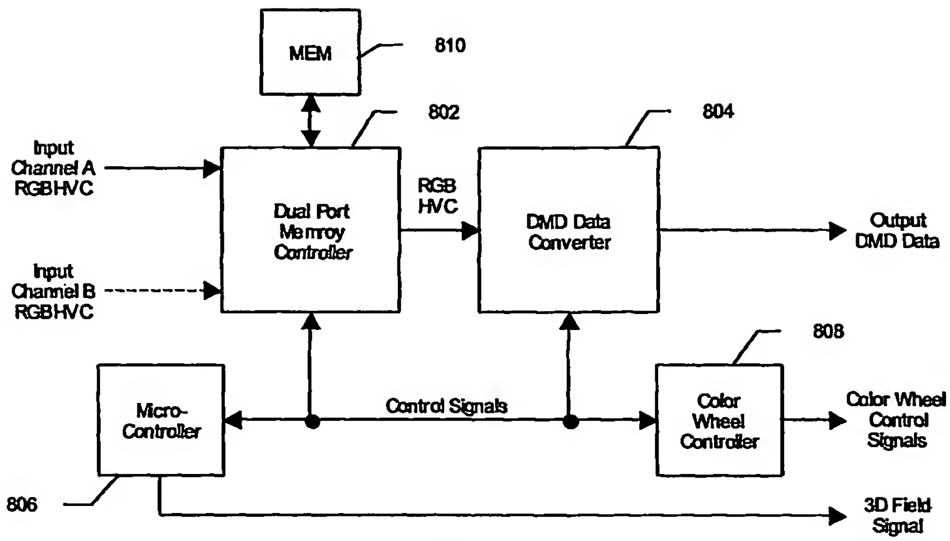



**Figure 7 - 3D Data Formatter Block Diagram**




800

**Figure 8 - DMD Data Formatter Block Diagram**

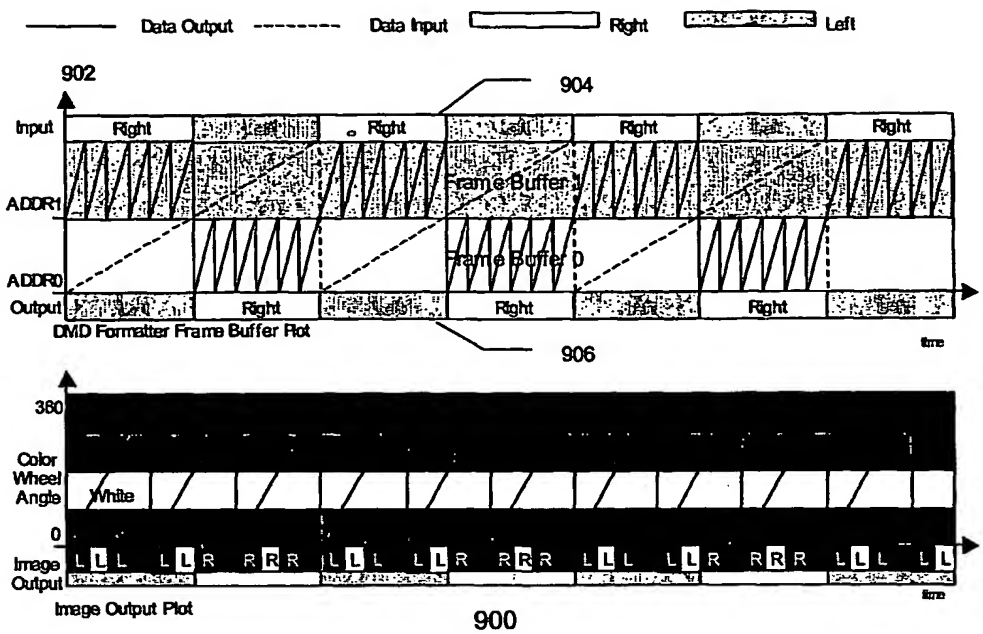



**Figure 9 - DMD Data Formatter Chart for Input Synchronized Frame Sequential 3D Input Using Four-Segment Color Wheel (Chart applies to 75Hz, 80Hz, and 85Hz input signals)**

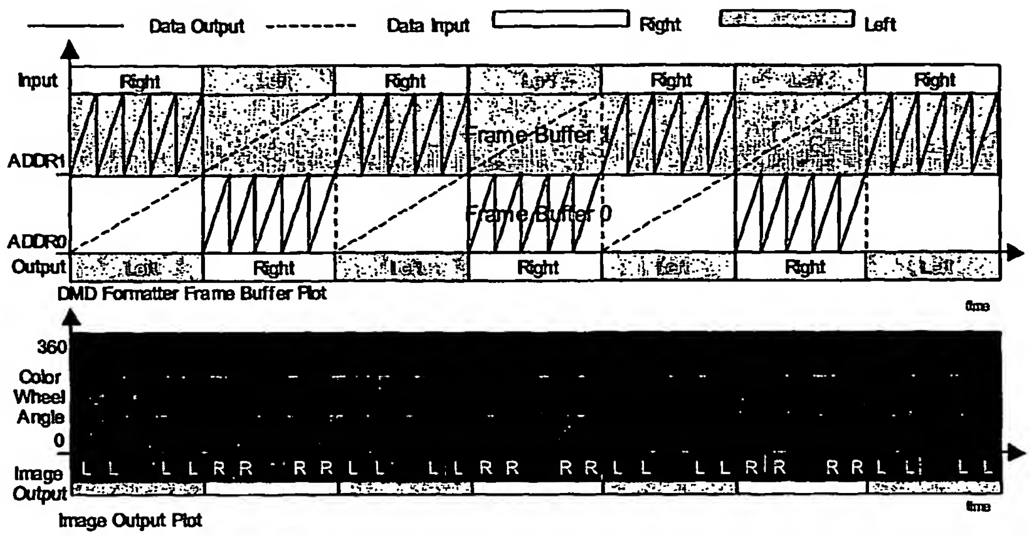



**Figure 10 - DMD Data Formatter Chart for Input Synchronized Frame Sequential 3D Input Using Three-Segment Color Wheel (Chart applies to 72Hz, 75Hz, and 80Hz input signals)**

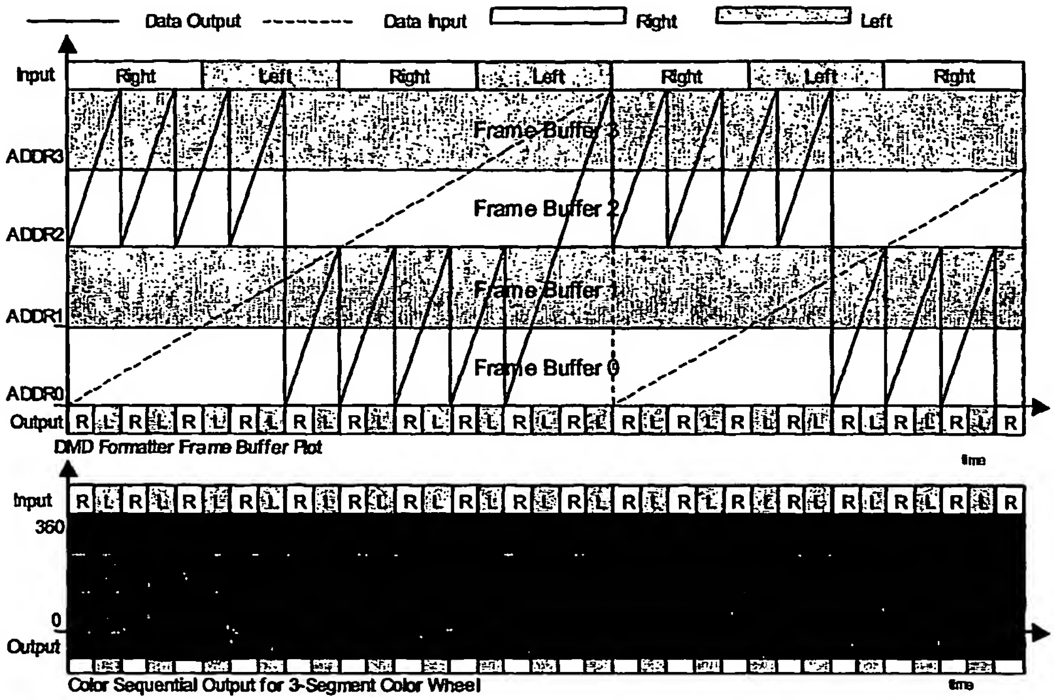



**Figure 11 - Input Synchronized Color Sequential 3D Using a Three Segment Color Wheel and Quad Frame Buffer (Chart applies to 72Hz, 75Hz, and 80Hz input signals)**

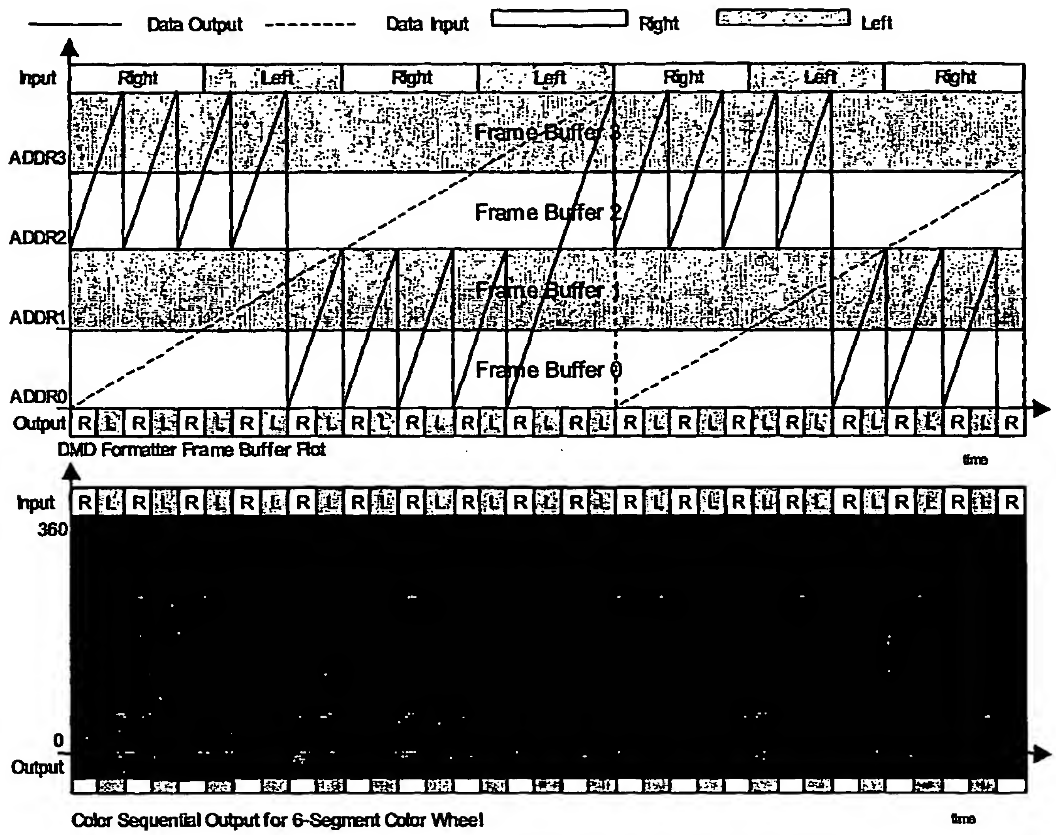



**Figure 12 - Input Synchronized Color Sequential 3D Using a Six-Segment Color Wheel and Quad Frame Buffer (Chart applies to 72Hz, 75Hz, and 80Hz input signals)**

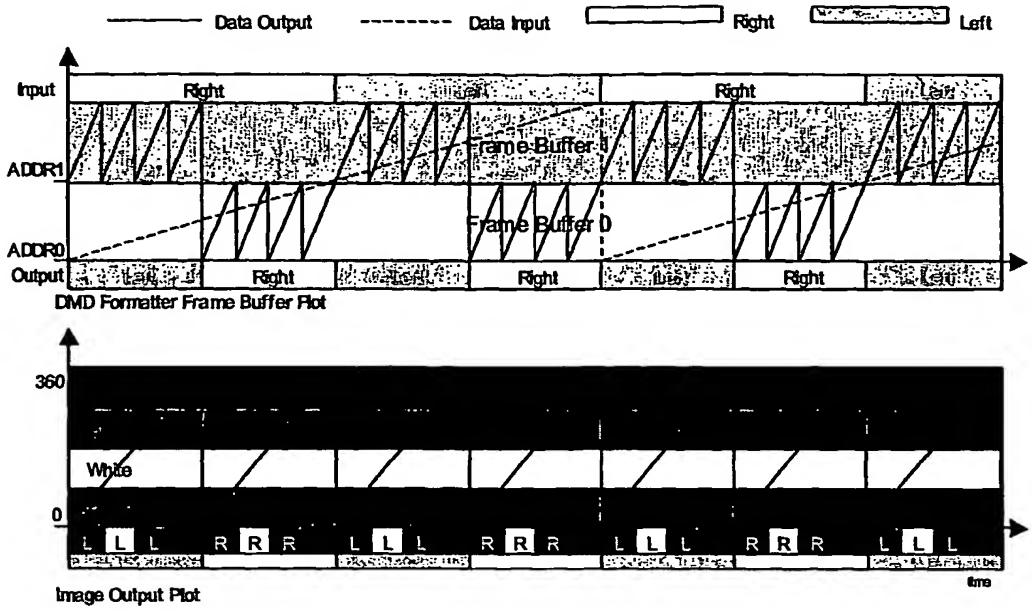



**Figure 13 - DMD Formatter Chart for Output Synchronized Frame Sequential 3D Format for 60Hz Input Using a Four-Segment Color Wheel**

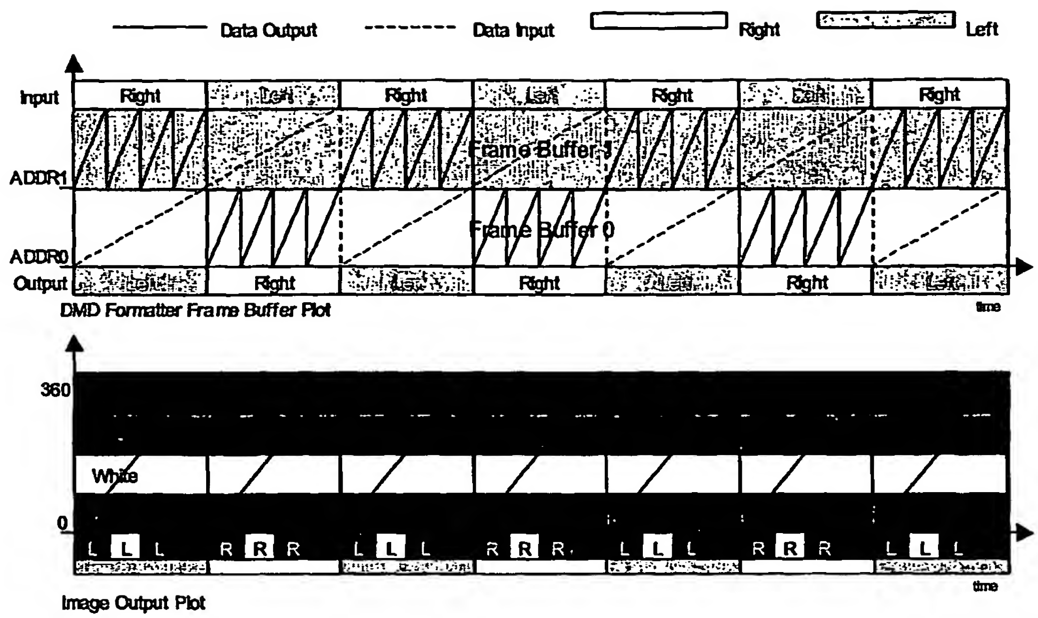



**Figure 14 - DMD Formatter Chart for Output Synchronized Frame Sequential 3D Format for 120Hz Input Using a Four-Segment Color Wheel**

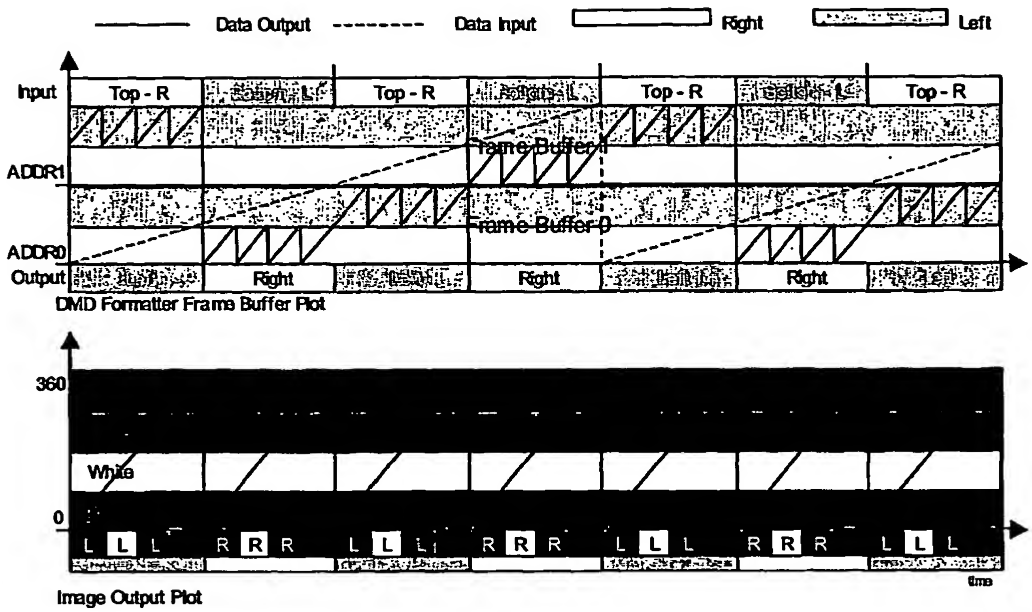



**Figure 15 - DMD Formatter Chart for Output Synchronized Frame-Sequential 3D Format for 60Hz Over-Under 3D Input using a Four-Segment Color Wheel**

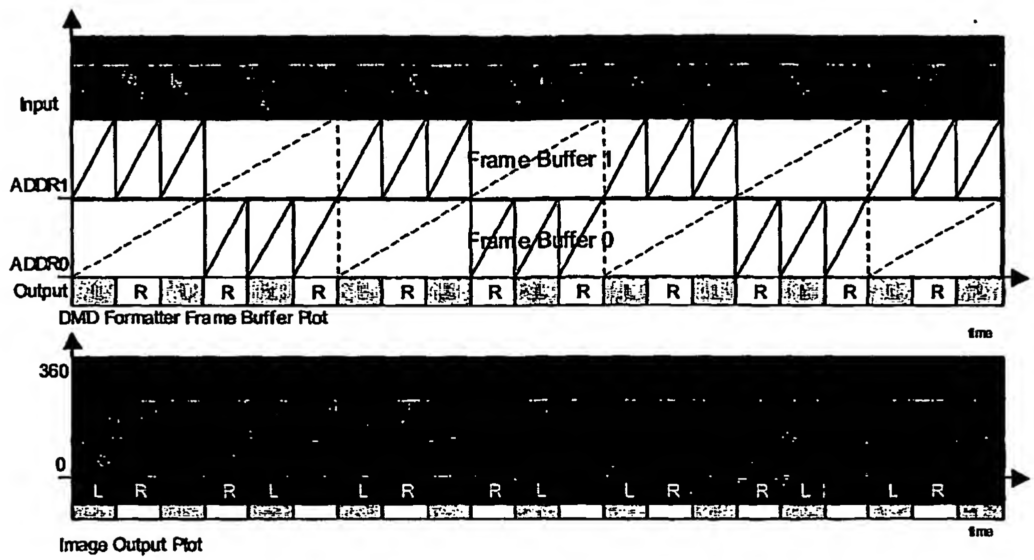



**Figure 16 - DMD Formatter Chart for Output Synchronized Color Sequential 3D Format for 120Hz Color-Sequential 3D Input, Using a Three-Segment Color Wheel**

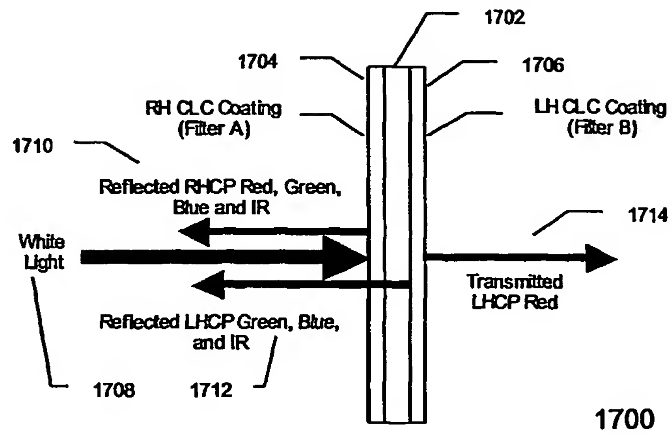
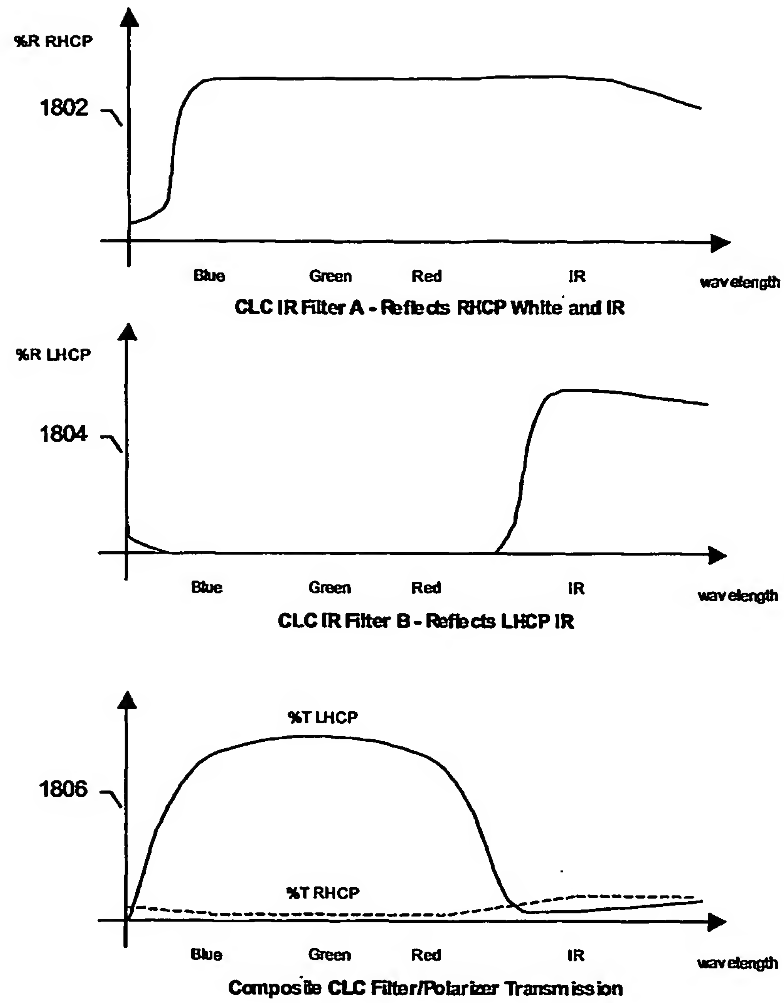



**Figure 17 - Cholosteric Liquid Crystal Reflective Circular Polarizing Red Filter (Similar for White, Green, or Blue)**




1800

Figure 18 - Spectral Response for CLC IR Filter/Circular Polarizer

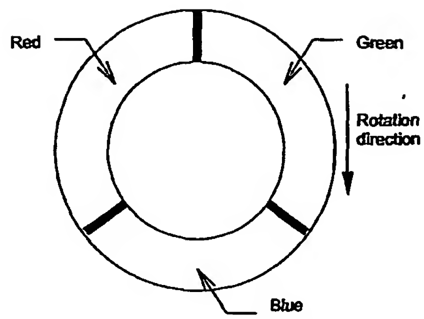



Figure 19 - Three-Segment Color Wheel Type CW-A

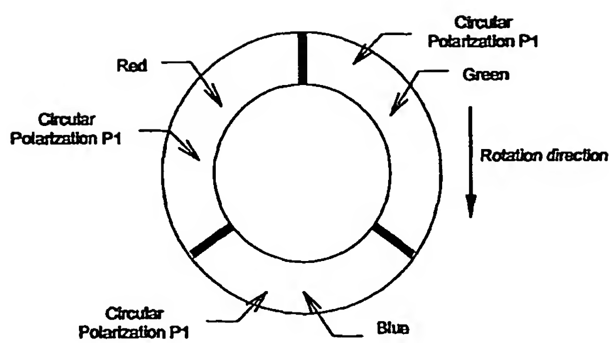



**Figure 20 - Three-Segment Color Wheel Type CW-B**

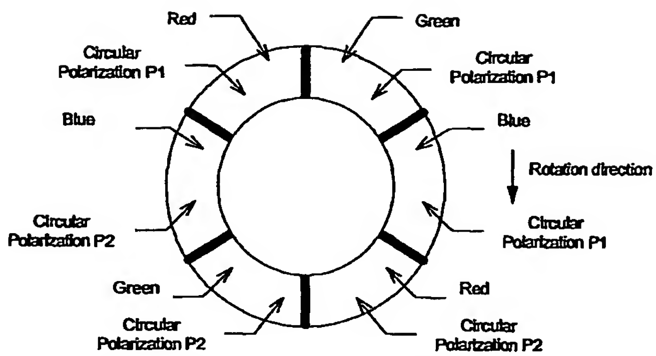



**Figure 21 - Six-Segment Color Wheel Type CW-C**

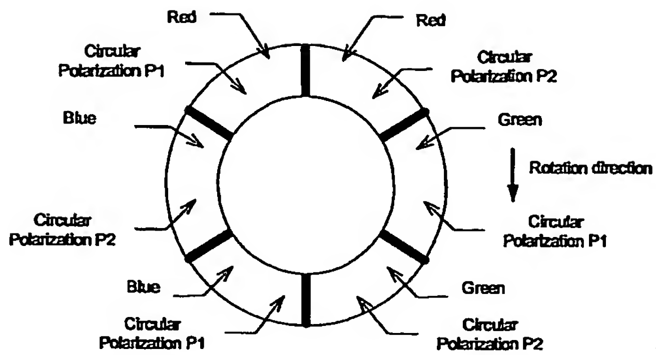



**Figure 22 - Six-Segment Color Wheel Type CW-D**

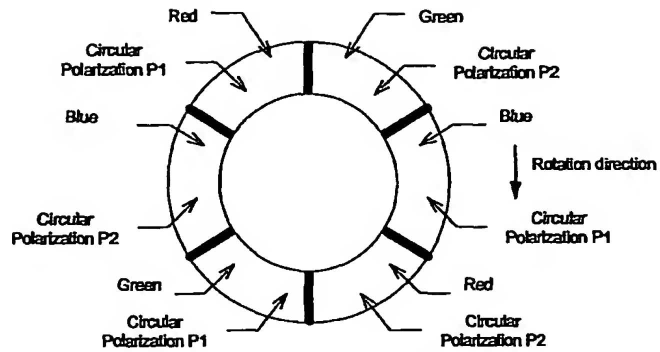



**Figure 23 - Six-Segment Color Wheel Type CW-E**

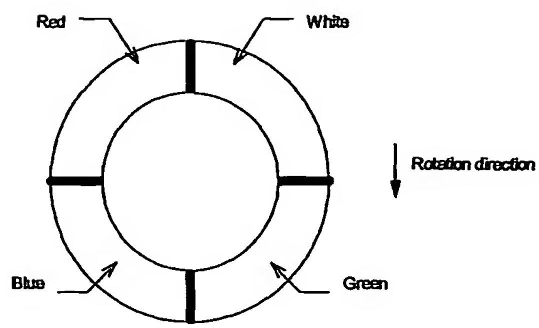



**Figure 24 - Four-Segment Color Wheel Type CW-F**

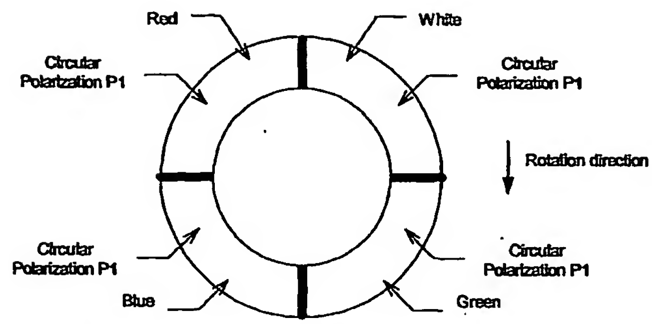



**Figure 25 - Four-Segment Color Wheel Type CW-G**

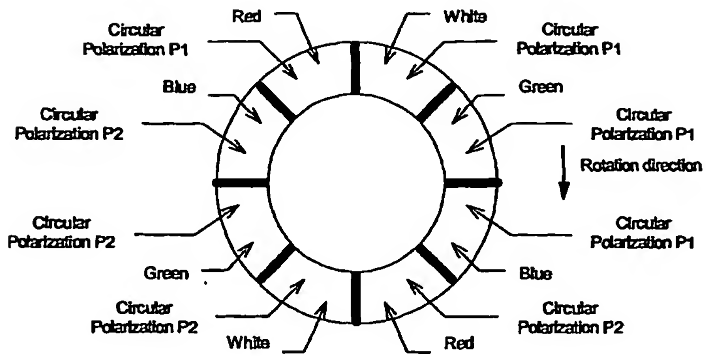



Figure 26 - Eight-Segment Color Wheel Type CW-H

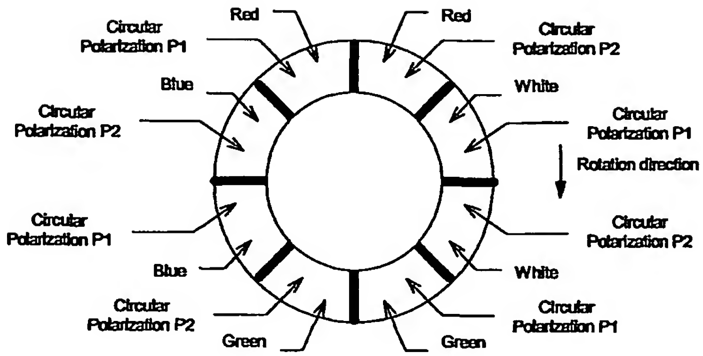



Figure 27 - Eight-Segment Color Wheel Type CW-I

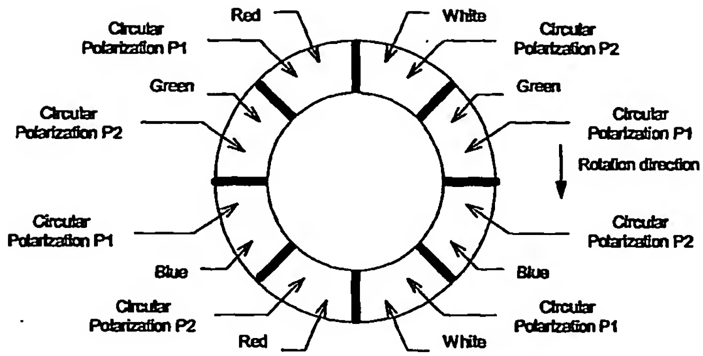



Figure 28 - Eight-Segment Color Wheel Type CW-J

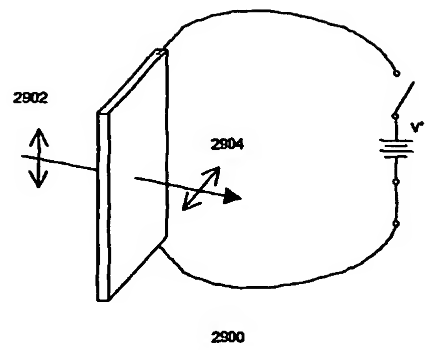



**Figure 29 - Liquid Crystal Rotator with no Applied Terminal Voltage**

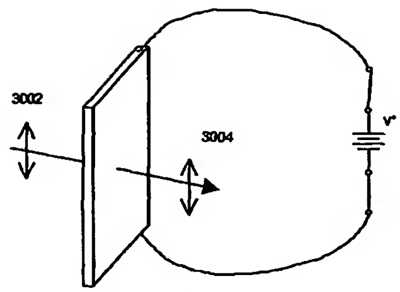



**Figure 30 - Liquid Crystal Rotator with Applied Terminal Voltage**

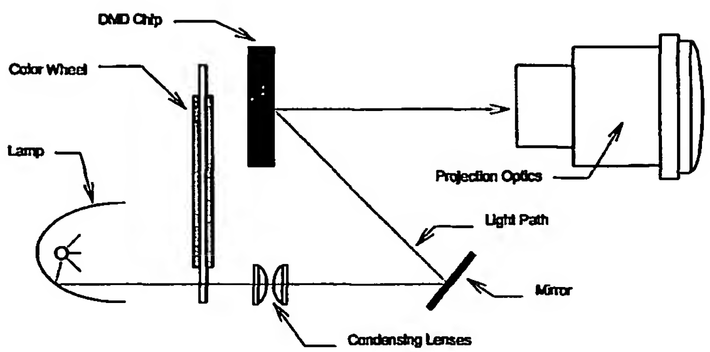



**Figure 31 - DMD Based Stereo 3D Projector, 3D Optical Configurations: A, B, H, I, K, M, N, S, U, W**

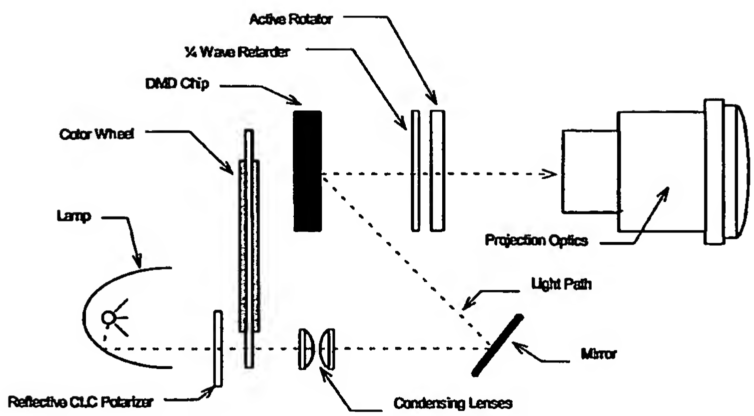



**Figure 32. DMD Based Stereo 3D Projector, 3D Optical Configurations: C and O**

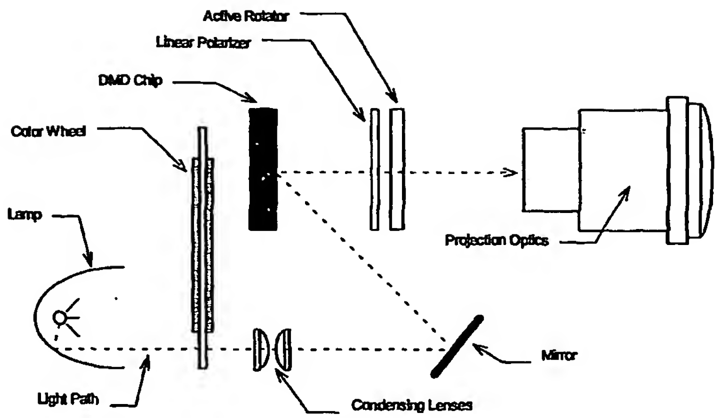



**Figure 33. DMD Based Stereo 3D Projector, 3D Optical Configurations: D and P**

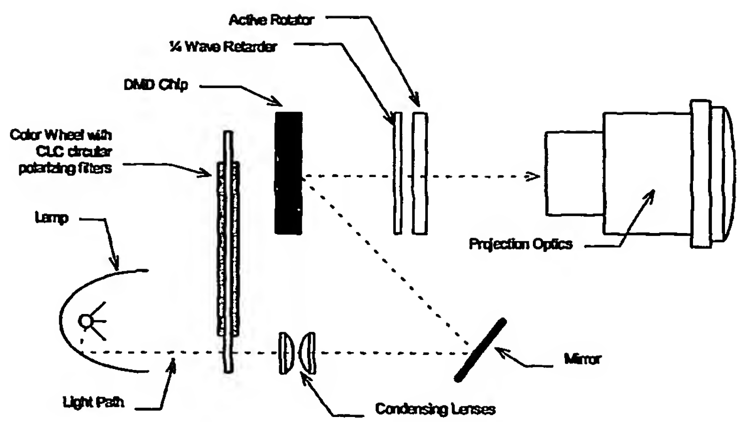



**Figure 34 - DMD Based Stereo 3D Projector, 3D Optical Configurations: E and Q**

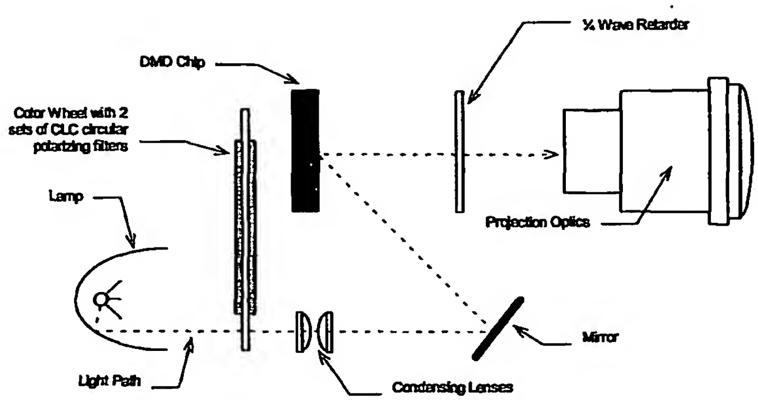



**Figure 35 - DMD Based Stereo 3D Projector, 3D Optical Configurations: F, G, J, L, R, T, and V**

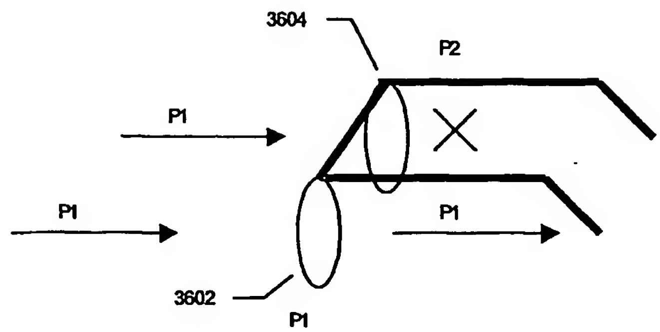
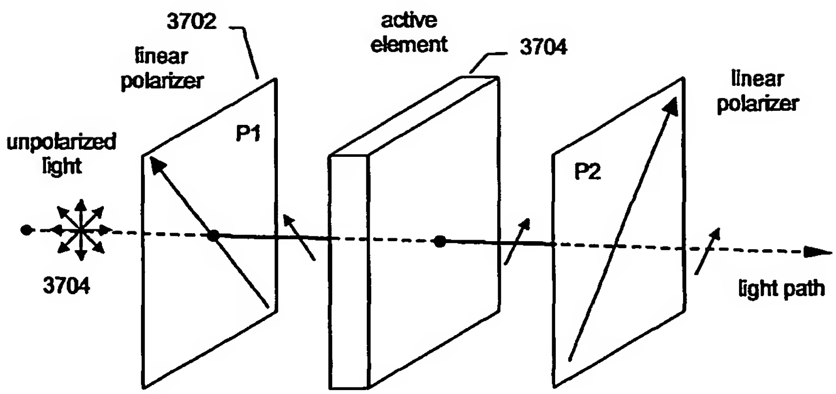



Figure 36 - Passive 3D Glasses (Linear or Circular Polarized)




3700

**Figure 37. Diagram of Typical LC Shutter Operation (Shutter Passing Light)**

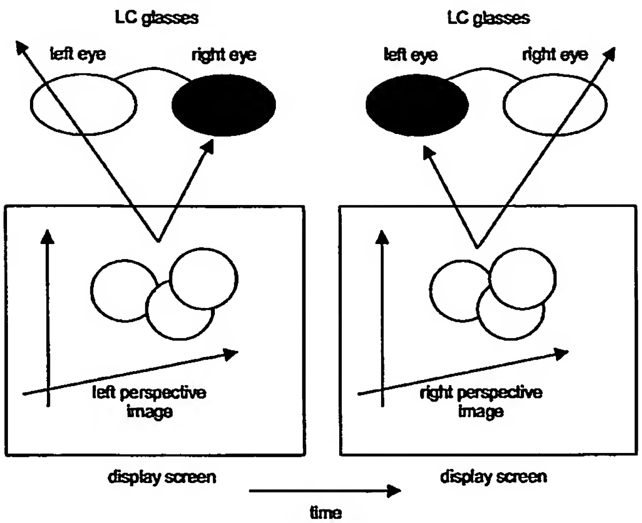



**Figure 38 - Use of LC Shutter Glasses in Stereoscopic Visualization**

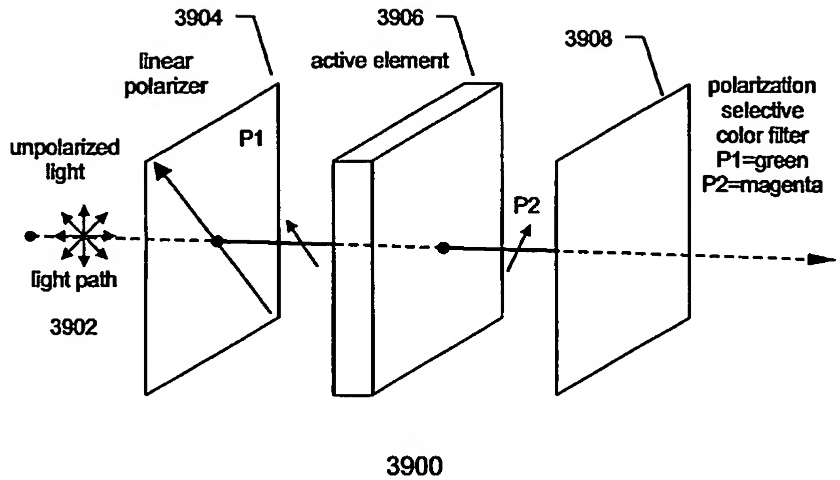



**Figure 39 - Conceptual Diagram of Switchable Color Filter for Eyewear used to Decode Color-Sequential 3D Formats**